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(54) **METHOD AND APPARATUS FOR LTE UPLINK THROUGHPUT ESTIMATION**

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H04L 12/26	(2006.01)
H04W 24/08	(2009.01)
H04W 28/02	(2009.01)
H04W 72/12	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 24/08*** (2013.01); ***H04W 28/0205*** (2013.01); *H04W 72/1252* (2013.01)

(58) **Field of Classification Search**

CPC H04W 28/0231; H04W 24/08; H04W 28/0205; H04W 72/1252

USPC 370/232–234, 253

See application file for complete search history.

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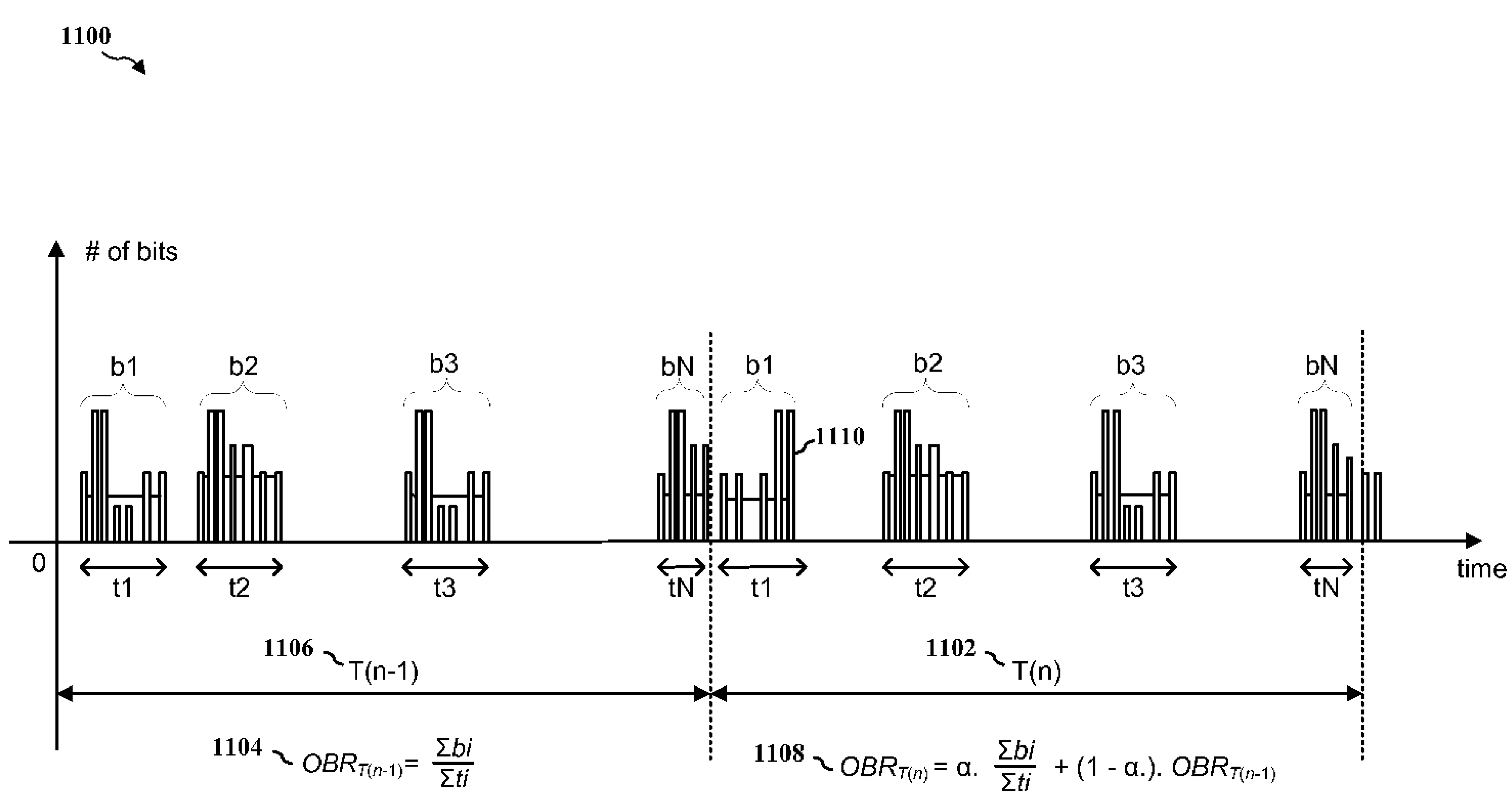
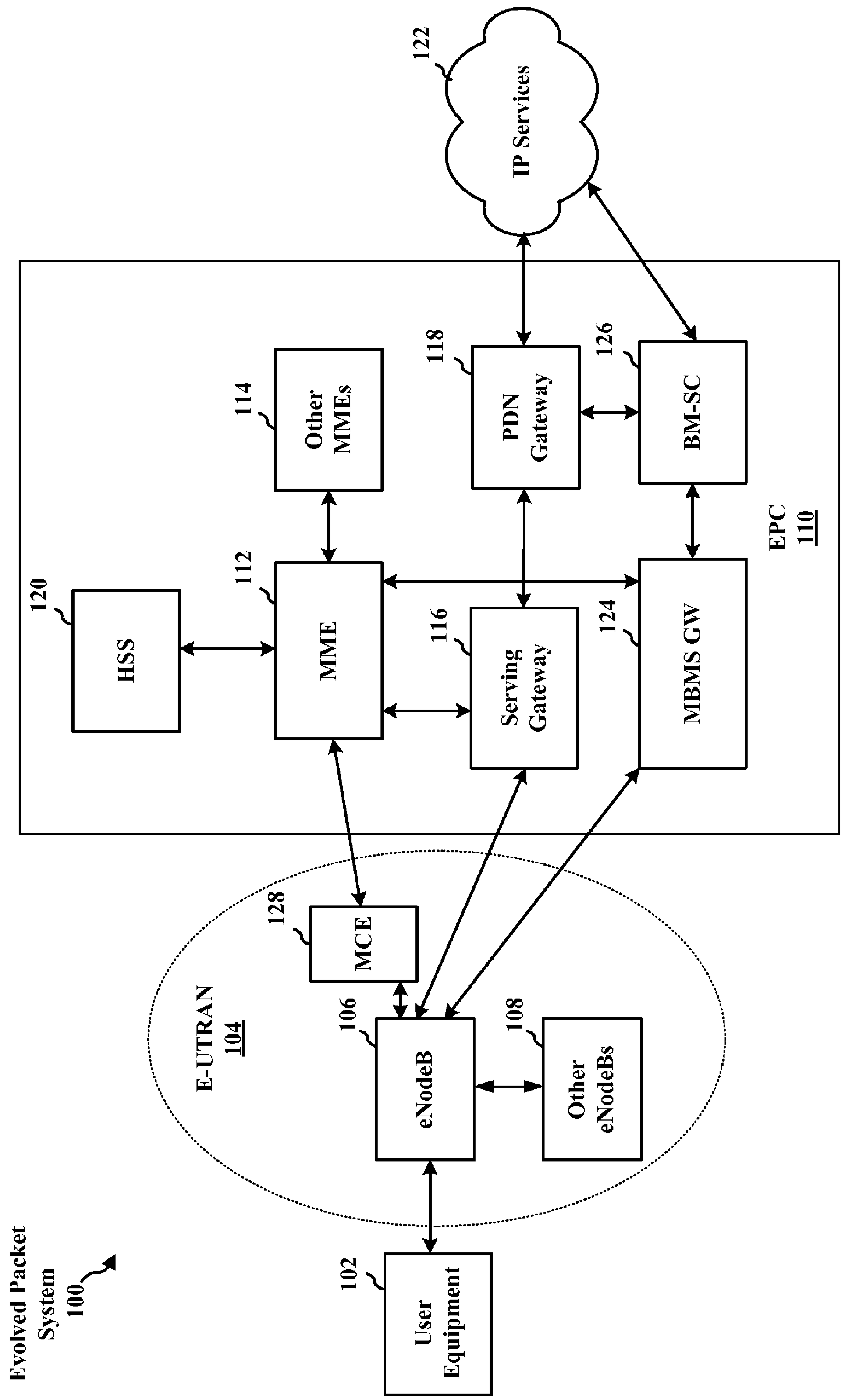
(57) **ABSTRACT**

A method, an apparatus, and a computer program product for wireless communication are provided. The apparatus determines an observed bit rate based on uplink transmissions of the UE, estimates an available link capacity for the UE, selects an estimate factor, and estimates available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor.

26 Claims, 15 Drawing Sheets





Evolved Packet System
100
User Equipment
102
E-UTRAN
104
eNodeB
106
Other eNodeBs
108
MCE
128
EPC
110
MME
112
Other MMEs
114
Serving Gateway
116
PDN Gateway
118
HSS
120
IP Services
122
MBMS GW
124
BM-SC
126

FIG. 1

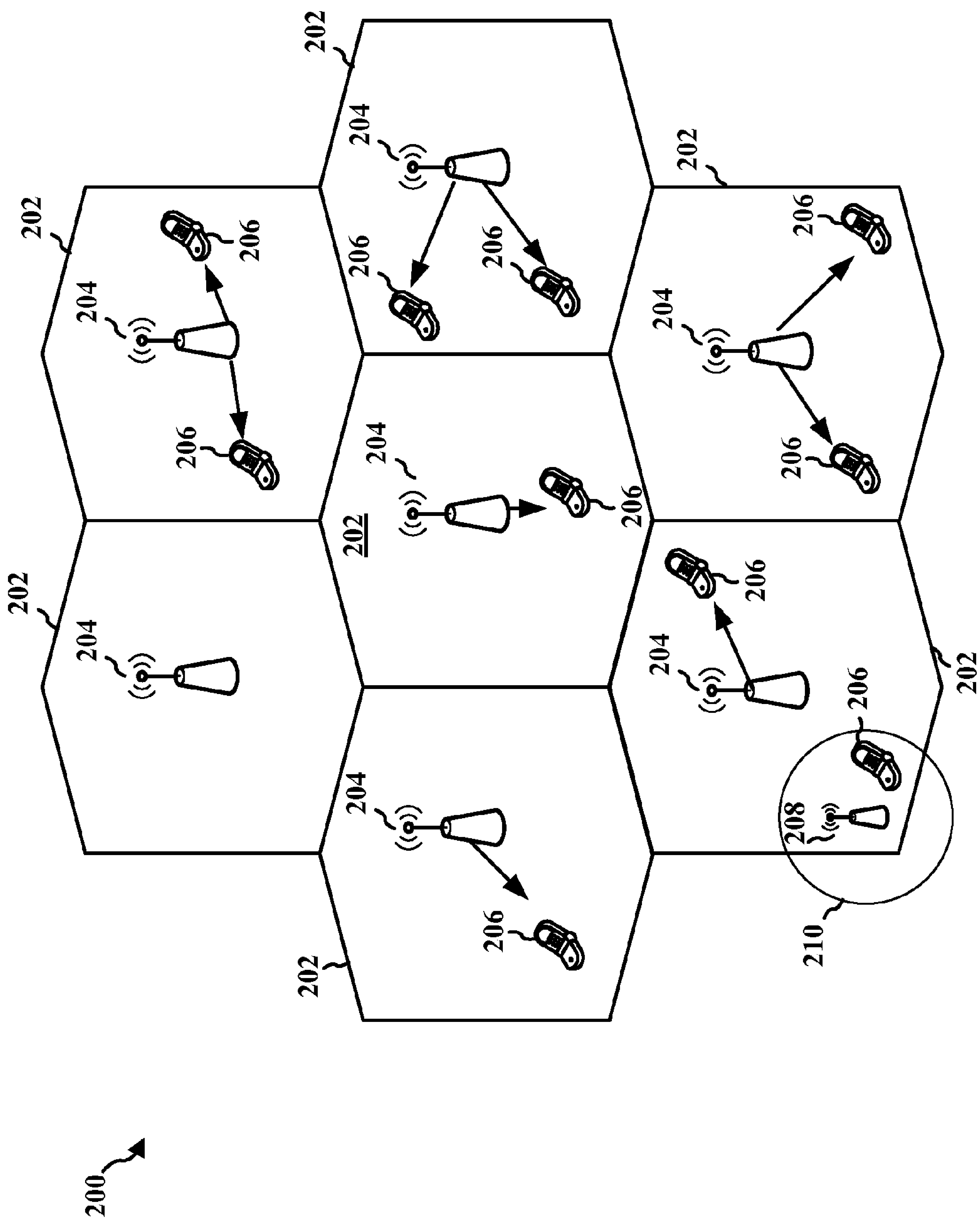


FIG. 2

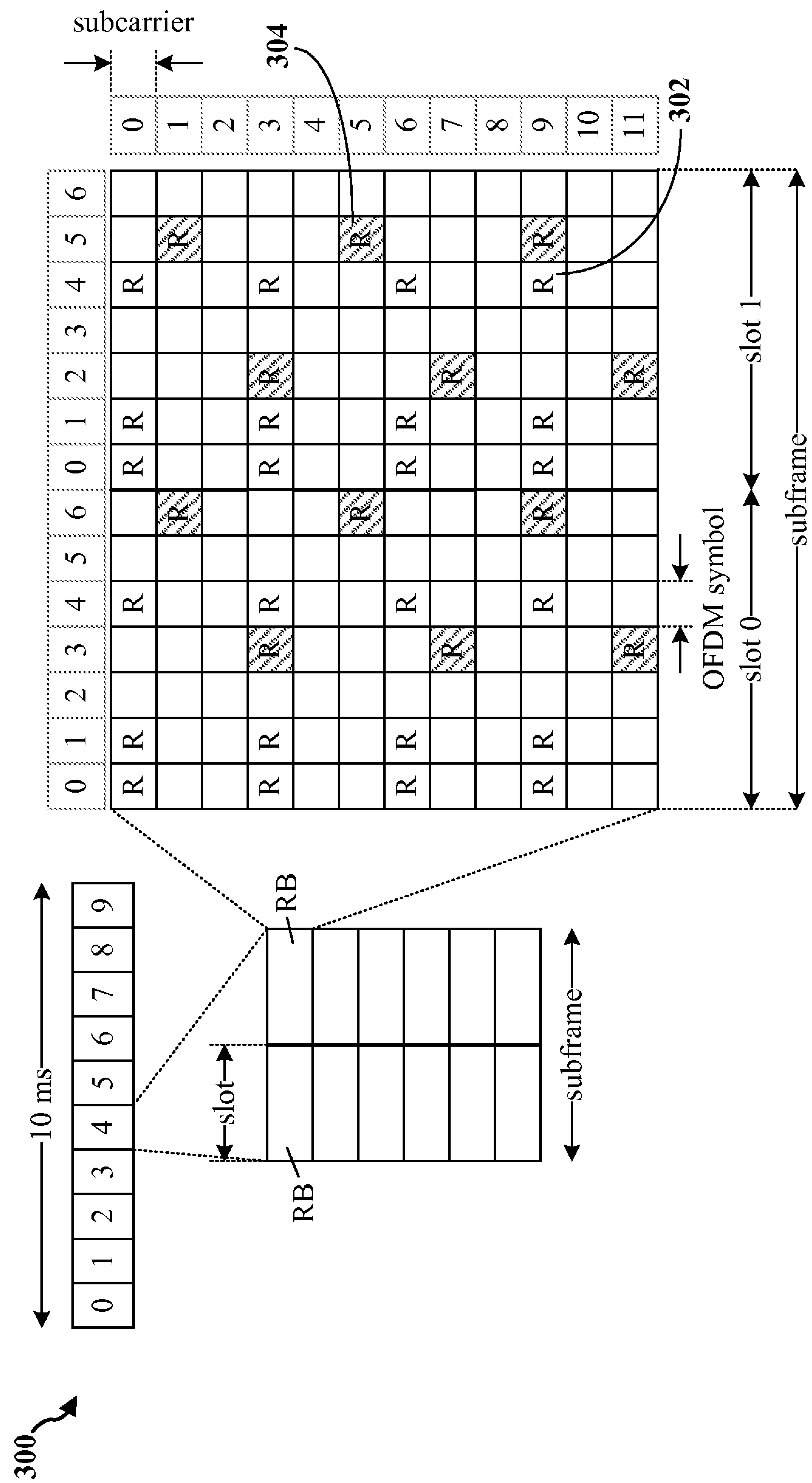

subcarrier
304
302
R
OFDM symbol
slot 0
slot 1
subframe
RB
slot
subframe
10 ms
300

FIG. 3

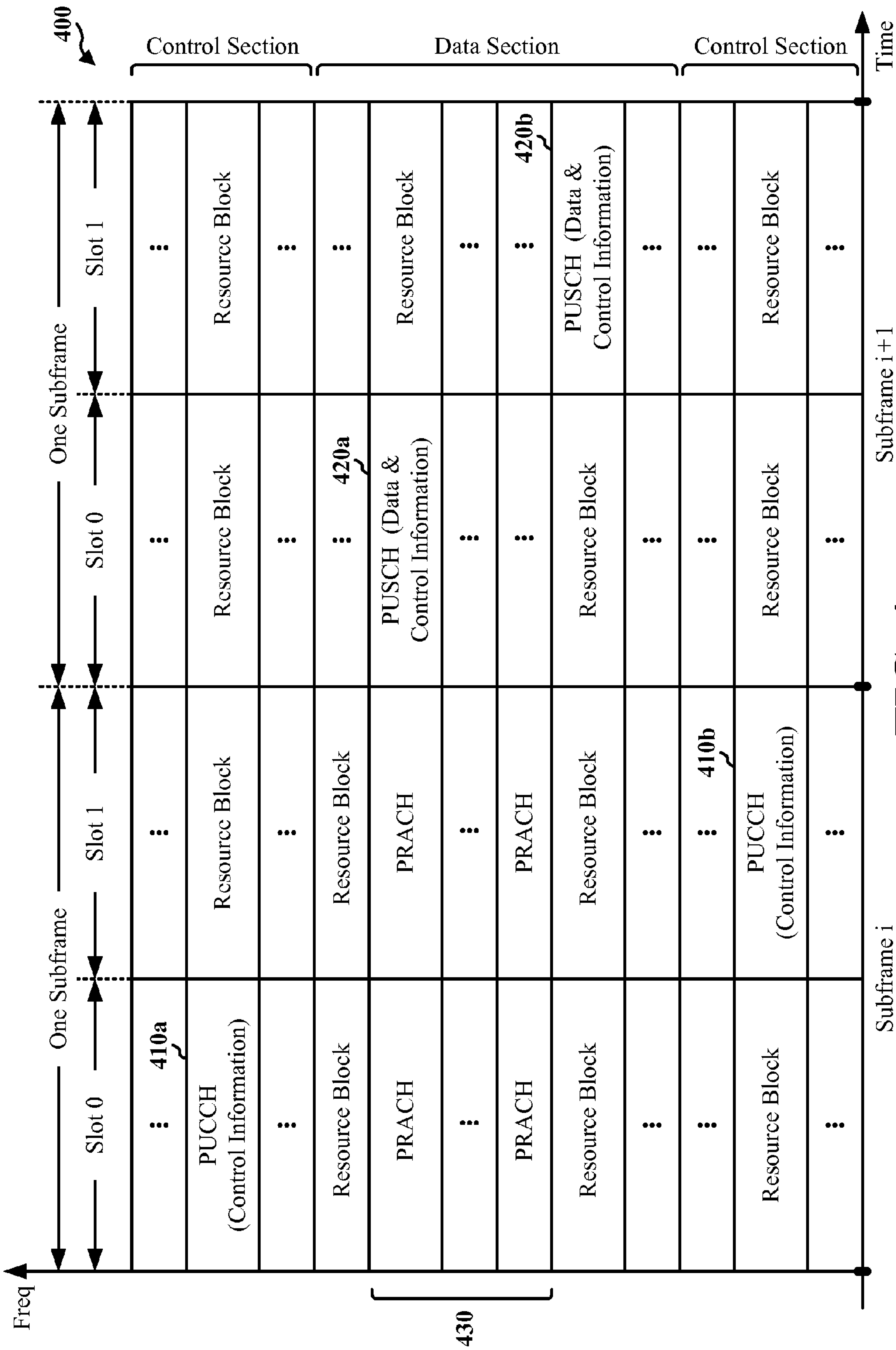
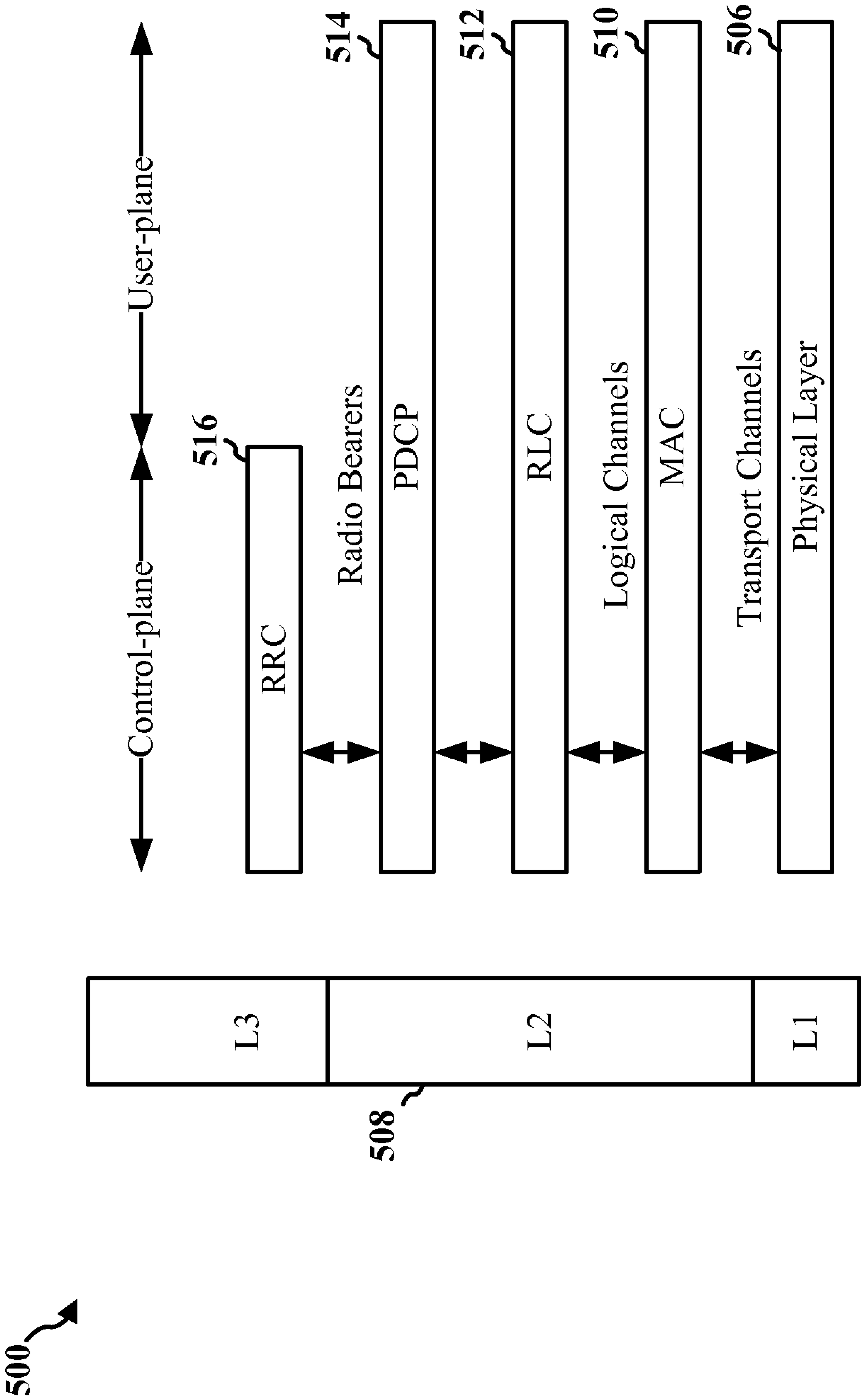

400
Control Section
Data Section
Control Section
Time
Freq
One Subframe
One Subframe
Slot 0
Slot 1
Slot 0
Slot 1
410a
PUCCH (Control Information)
410b
PUCCH (Control Information)
420a
PUSCH (Data & Control Information)
420b
PUSCH (Data & Control Information)
Resource Block
PRACH
PRACH
430
Subframe i
Subframe i+1

FIG. 4



Control-plane
User-plane
516
RRC
Radio Bearers
514
PDCP
512
RLC
Logical Channels
510
MAC
Transport Channels
506
Physical Layer
L3
L2
L1
508
500

FIG. 5

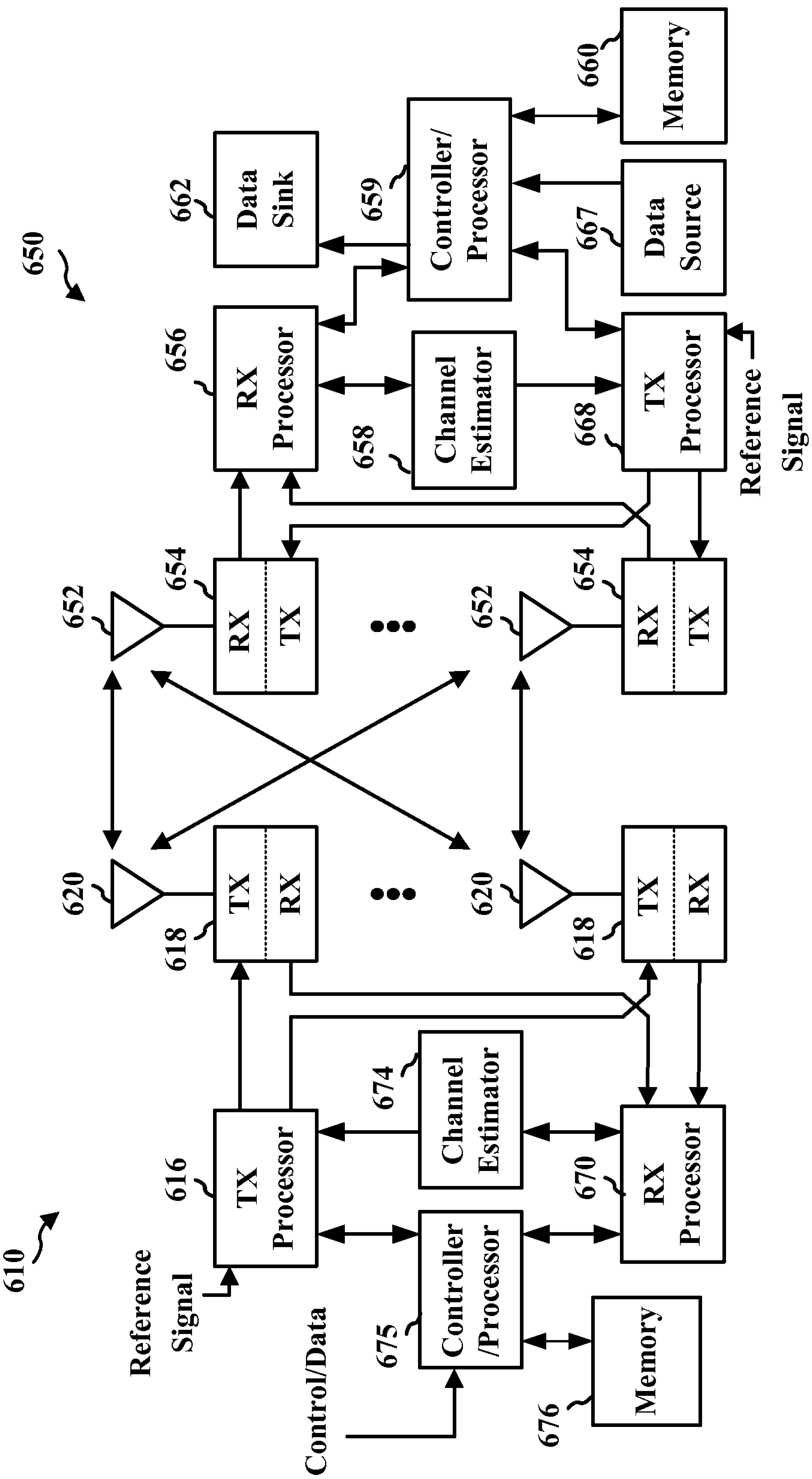

650
610
662
Data Sink
659
Controller/ Processor
660
Memory
667
Data Source
656
RX Processor
658
Channel Estimator
668
TX Processor
Reference Signal
654
RX
TX
652
620
618
TX
RX
616
TX Processor
674
Channel Estimator
670
RX Processor
675
Controller /Processor
676
Memory
Reference Signal
Control/Data

FIG. 6

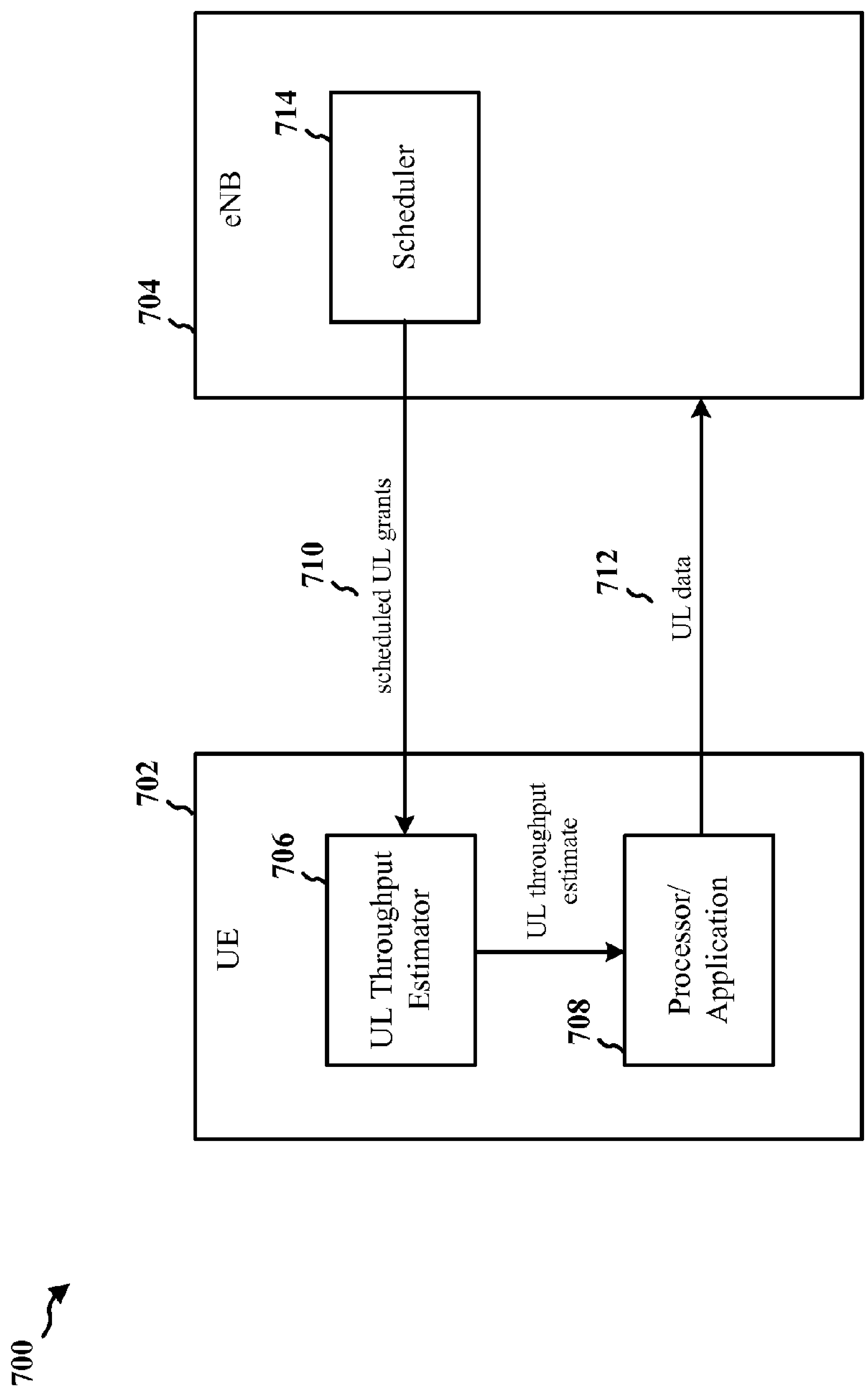

700
UE
702
706
UL Throughput Estimator
UL throughput estimate
708
Processor/ Application
710
scheduled UL grants
712
UL data
eNB
704
714
Scheduler

FIG. 7

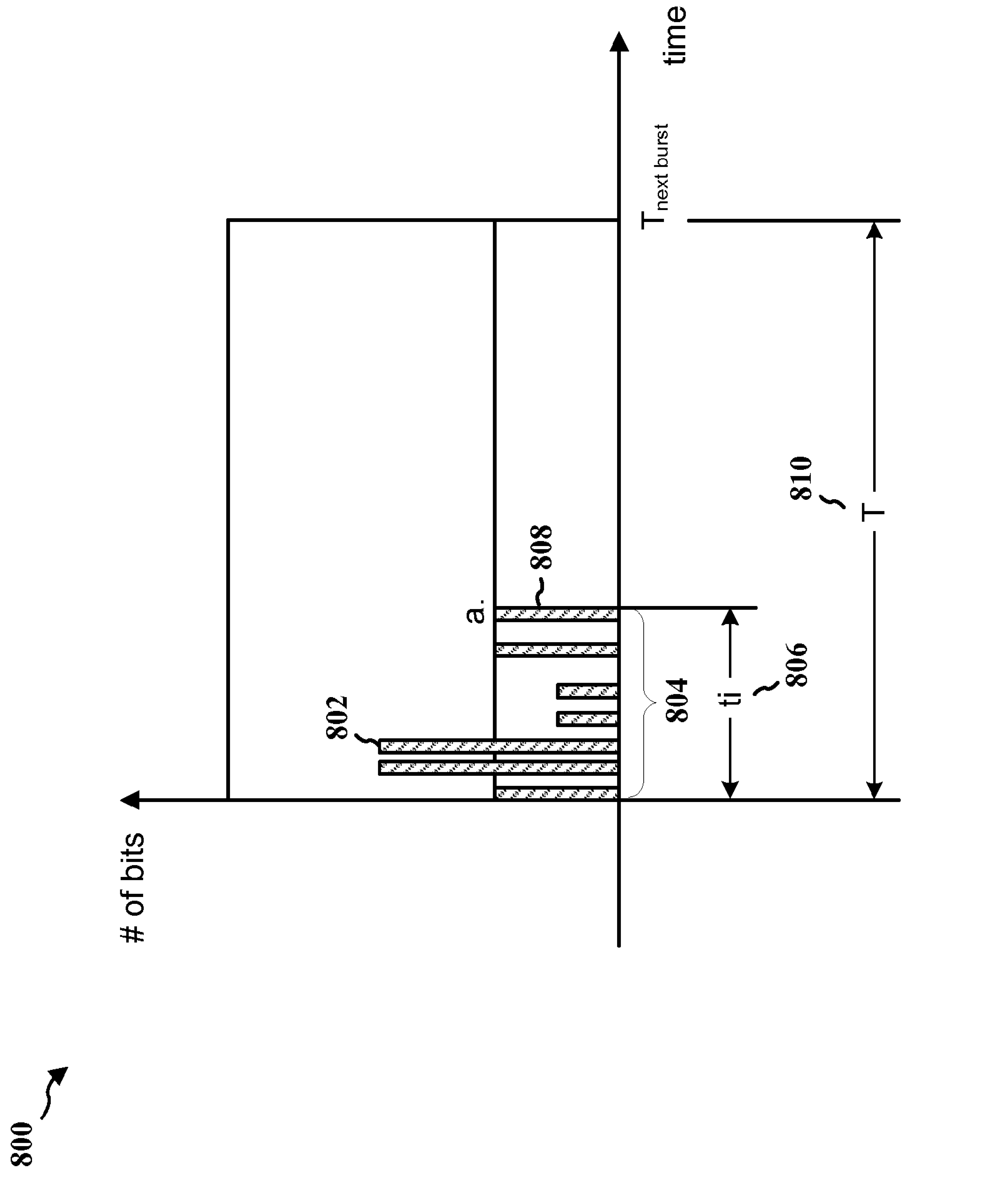
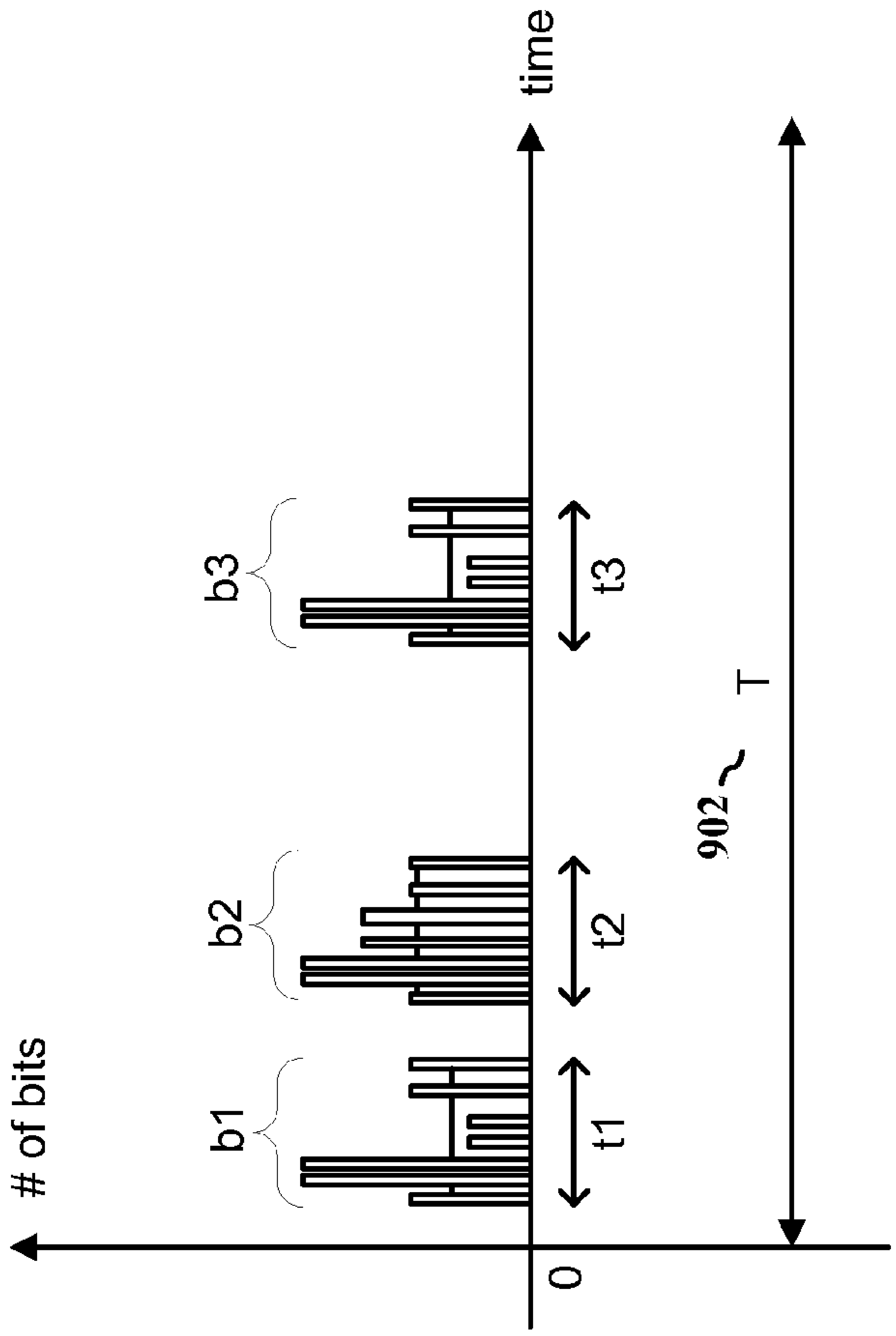


FIG. 8

900



904 $OBRt1/t2 = \dfrac{\dfrac{b1}{t1} + \dfrac{b2}{t2}}{2}$

906 $OBR_T = \dfrac{OBRt1/t2 + \dfrac{b3}{t3}}{2}$

FIG. 9

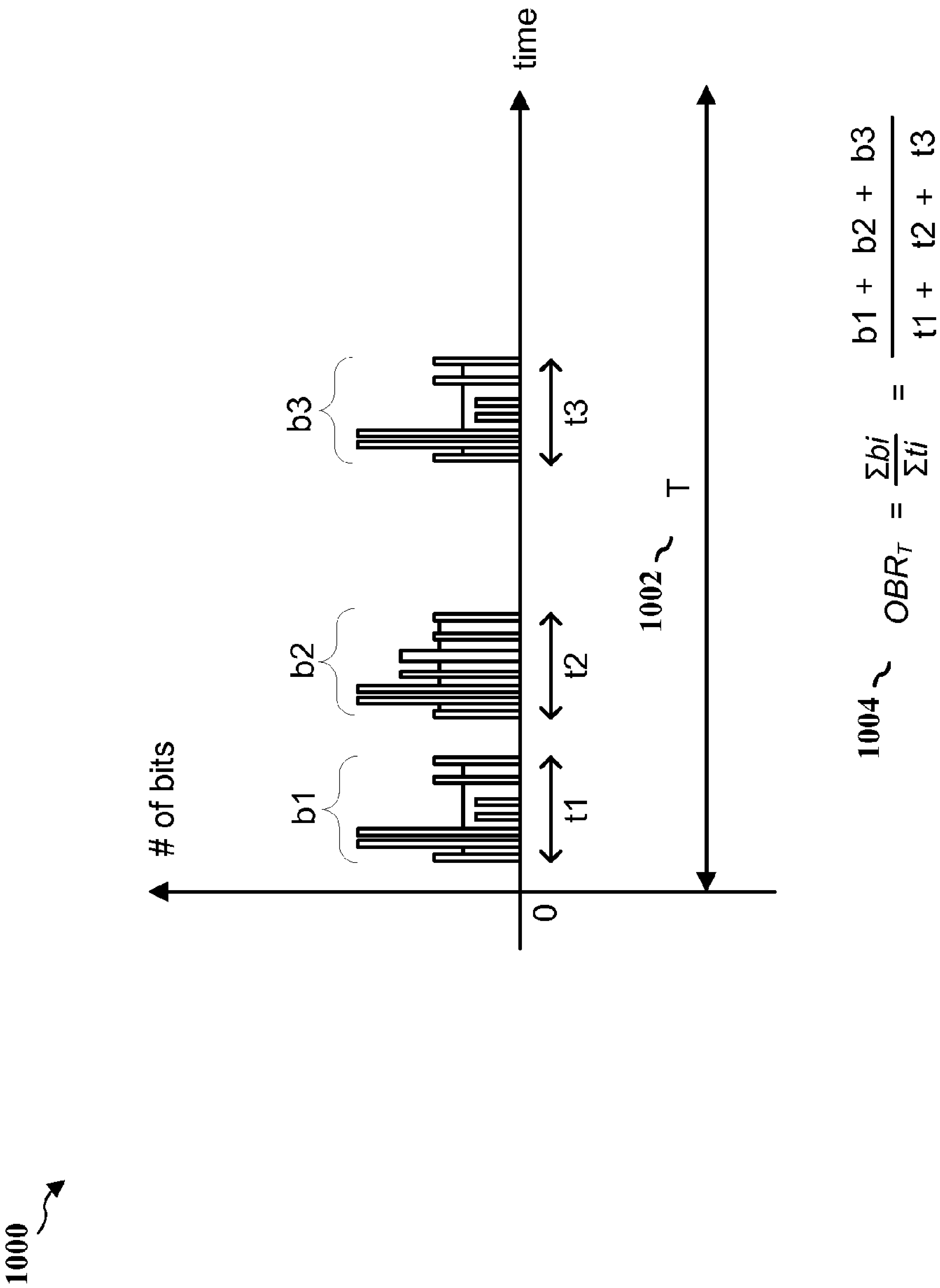

1000
# of bits
time
0
b1
b2
b3
t1
t2
t3
T
1002
1004
$OBR_T = \frac{\Sigma bi}{\Sigma ti} = \frac{b1 + b2 + b3}{t1 + t2 + t3}$

FIG. 10

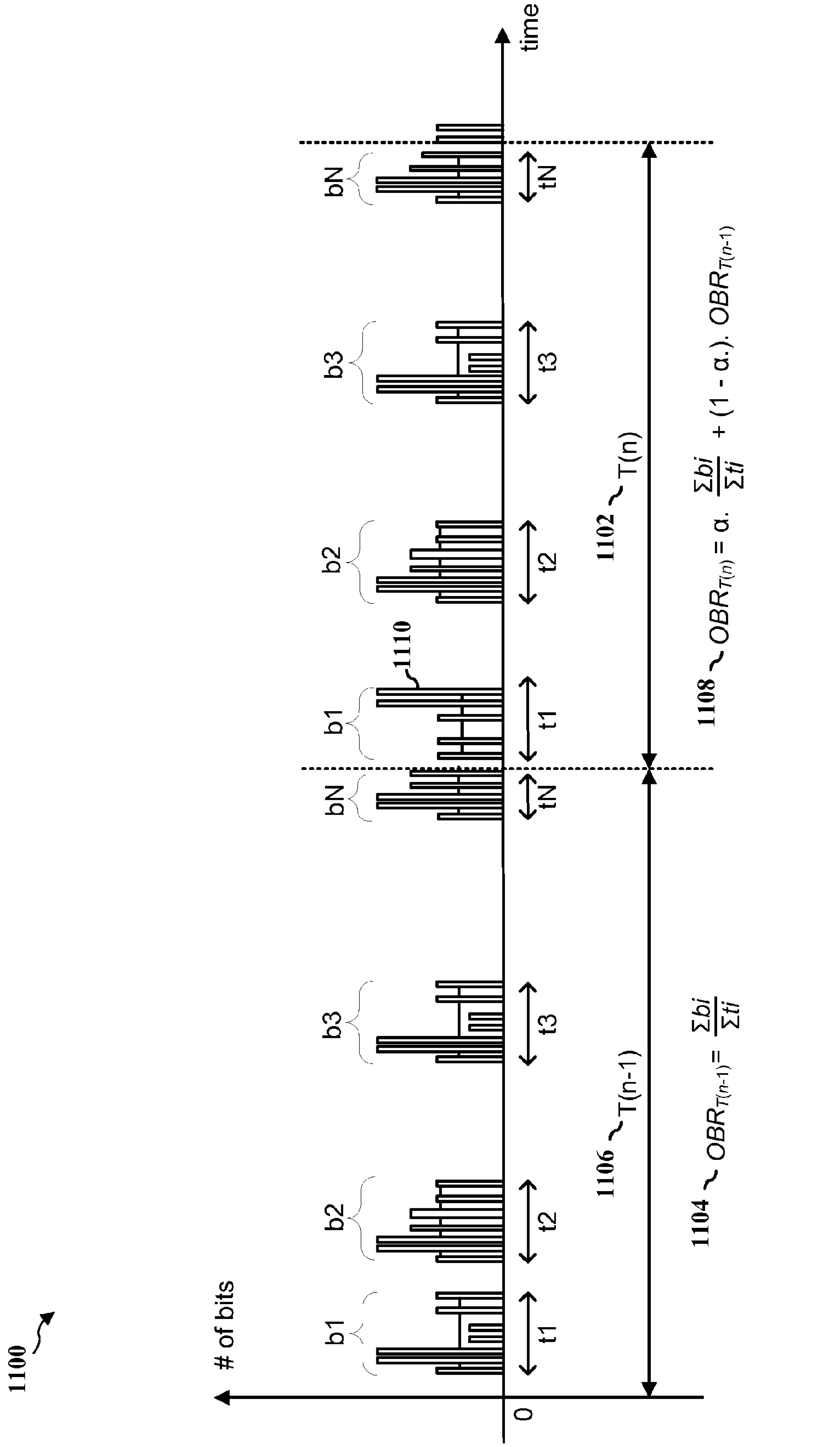

1100
# of bits
time
0
b1
b2
b3
bN
t1
t2
t3
tN
1110
1102 T(n)
1106 T(n-1)
1104 $OBR_{T(n-1)} = \frac{\Sigma bi}{\Sigma ti}$
1108 $OBR_{T(n)} = \alpha . \frac{\Sigma bi}{\Sigma ti} + (1 - \alpha .). OBR_{T(n-1)}$

FIG. 11

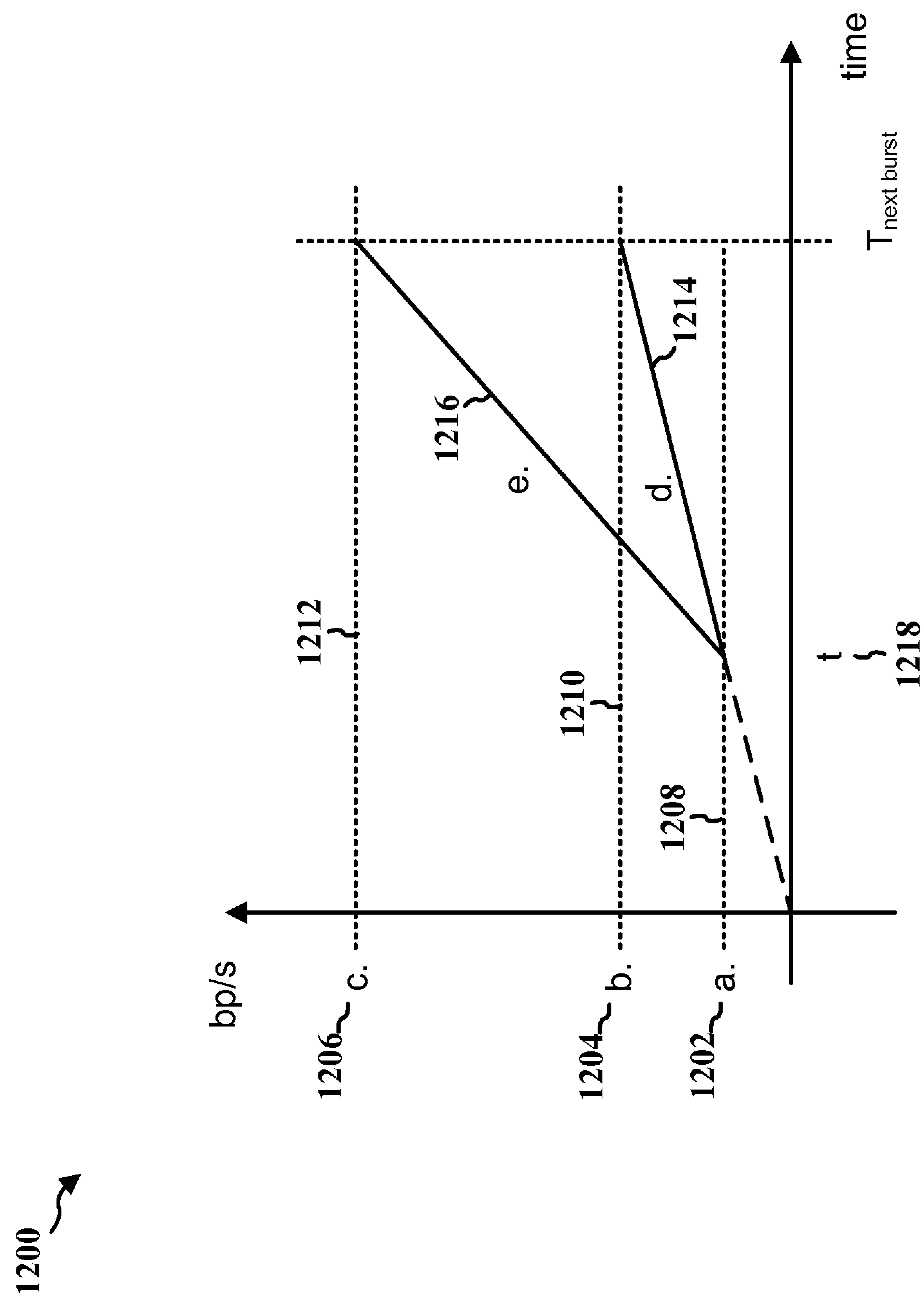

1200
bp/s
time
1206
c.
1204
b.
1202
a.
1212
1210
1208
1216
e.
1214
d.
t
1218
$T_{next\ burst}$

FIG. 12

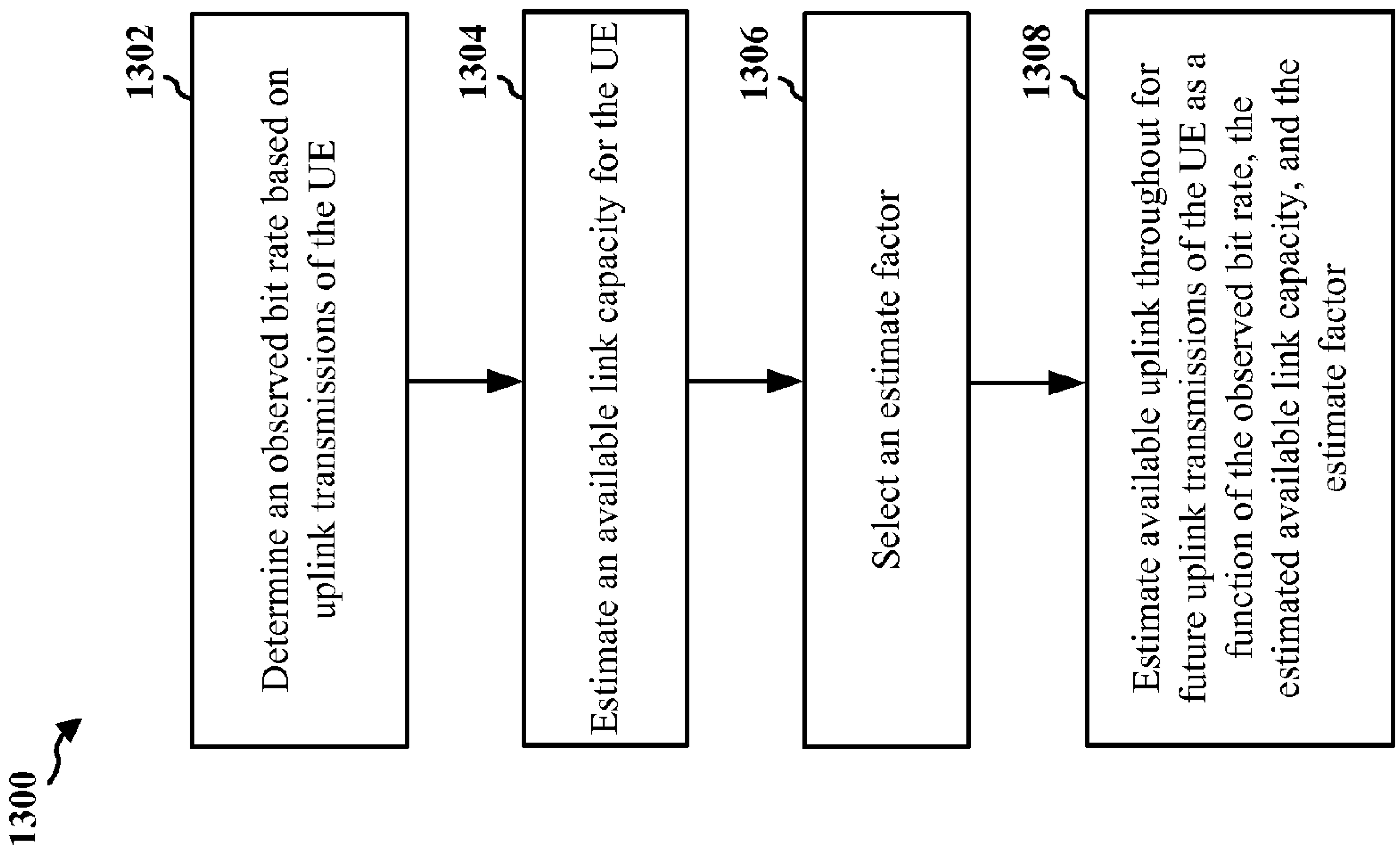

1300
1302
Determine an observed bit rate based on uplink transmissions of the UE
1304
Estimate an available link capacity for the UE
1306
Select an estimate factor
1308
Estimate available uplink throughout for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor

FIG. 13

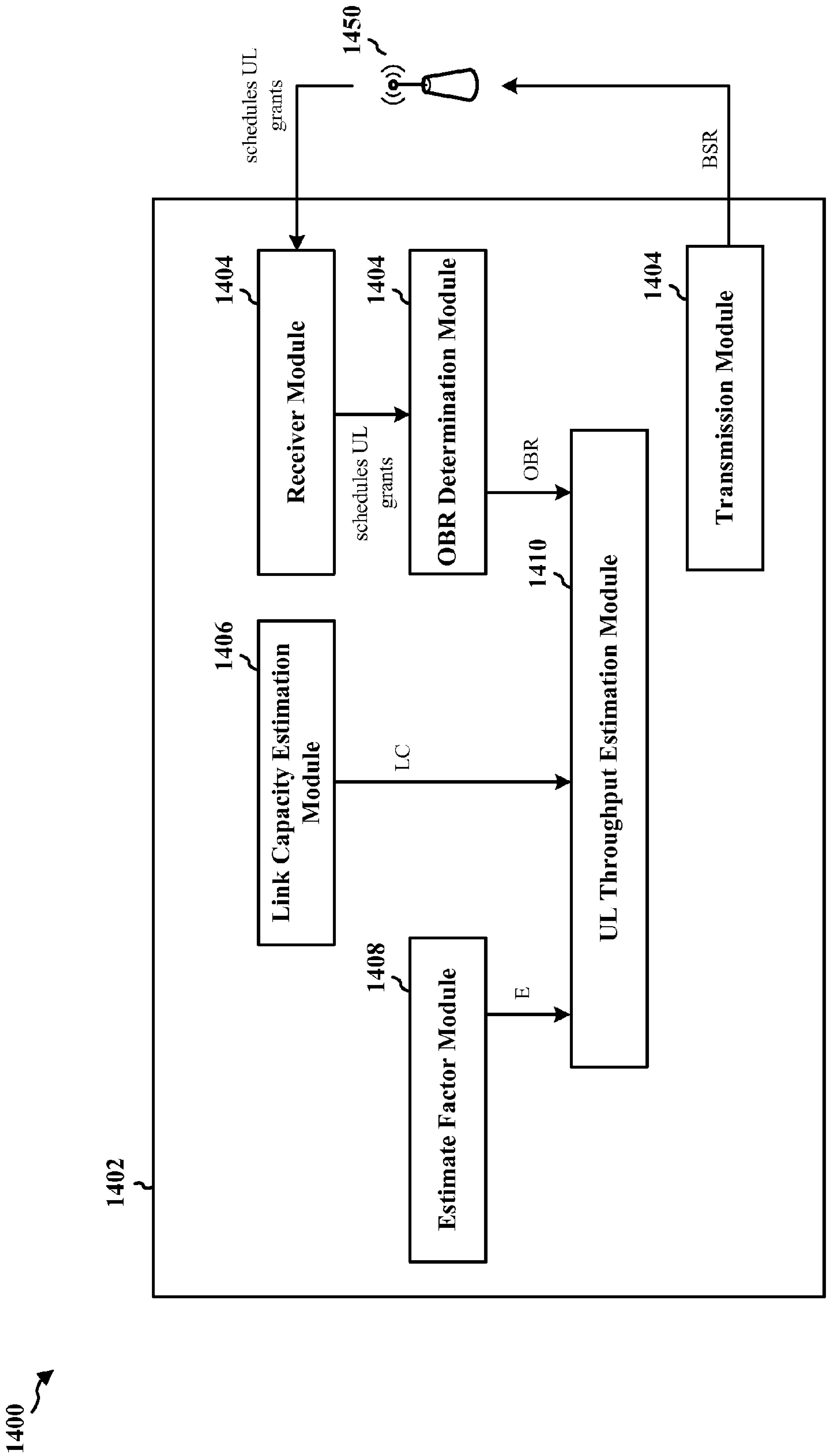

1450
schedules UL grants
BSR
1404
Receiver Module
1404
OBR Determination Module
1404
Transmission Module
schedules UL grants
OBR
1410
UL Throughput Estimation Module
1406
Link Capacity Estimation Module
LC
1408
Estimate Factor Module
E
1402
1400

FIG. 14

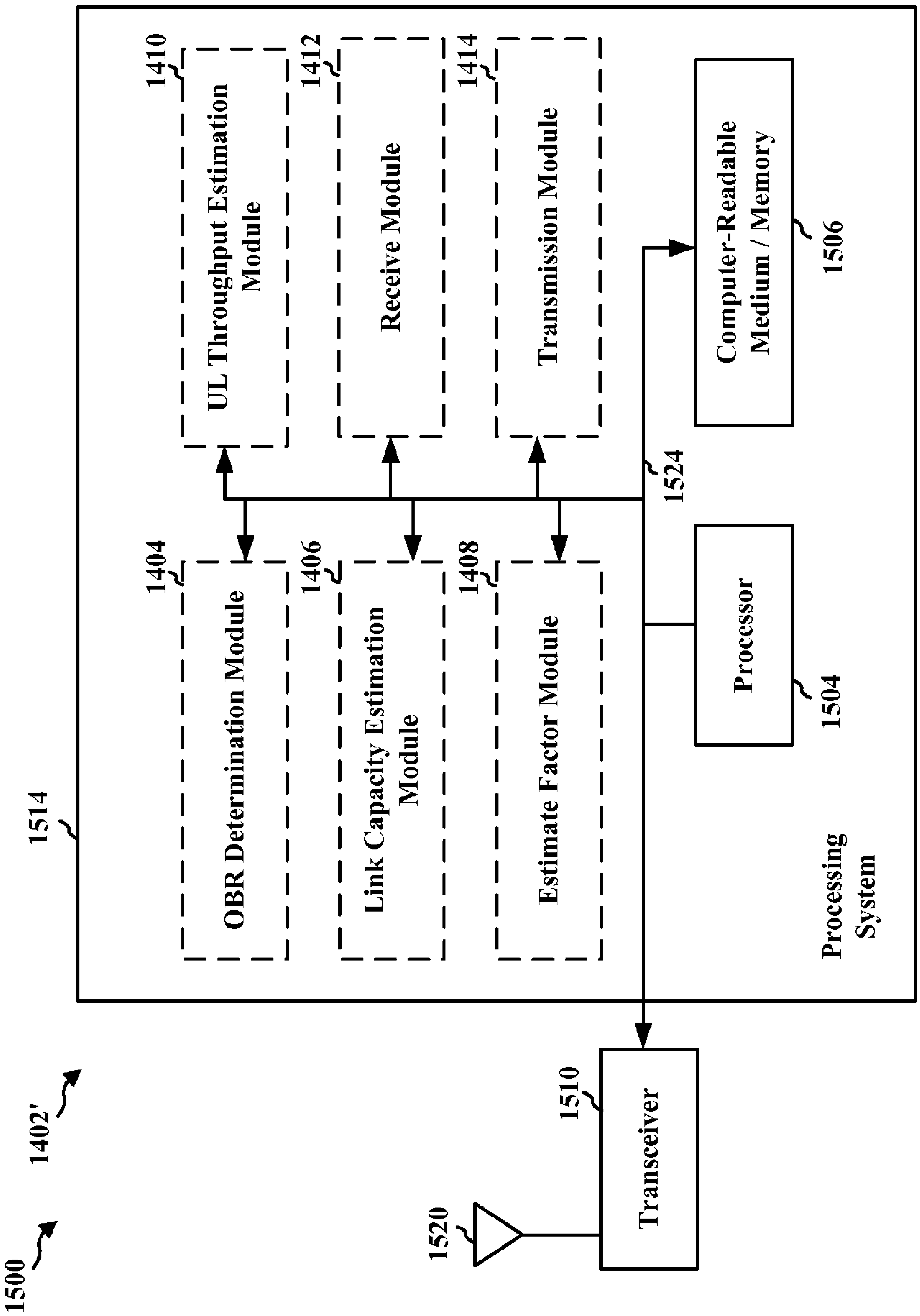

1500
1402'
1514
1410
UL Throughput Estimation Module
1412
Receive Module
1414
Transmission Module
1404
OBR Determination Module
1406
Link Capacity Estimation Module
1408
Estimate Factor Module
1524
Computer-Readable Medium / Memory
1506
Processor
1504
Processing System
1510
Transceiver
1520

FIG. 15

METHOD AND APPARATUS FOR LTE UPLINK THROUGHPUT ESTIMATION

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims the benefit of U.S. Provisional Application Ser. No. 61/901,370, entitled "Method and Apparatus for LTE Uplink Throughput Estimation" and filed on Nov. 7, 2013, which is expressly incorporated by reference herein in its entirety

BACKGROUND

1. Field

The present disclosure relates generally to communication systems, and more particularly, to methods and apparatuses for estimating uplink throughput for LTE.

2. Background

Wireless communication systems are widely deployed to provide various telecommunication services such as telephony, video, data, messaging, and broadcasts. Typical wireless communication systems may employ multiple-access technologies capable of supporting communication with multiple users by sharing available system resources (e.g., bandwidth, transmit power). Examples of such multiple-access technologies include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, orthogonal frequency division multiple access (OFDMA) systems, single-carrier frequency division multiple access (SC-FDMA) systems, and time division synchronous code division multiple access (TD-SCDMA) systems.

These multiple access technologies have been adopted in various telecommunication standards to provide a common protocol that enables different wireless devices to communicate on a municipal, national, regional, and even global level. An example of an emerging telecommunication standard is Long Term Evolution (LTE). LTE is a set of enhancements to the Universal Mobile Telecommunications System (UMTS) mobile standard promulgated by Third Generation Partnership Project (3GPP). It is designed to better support mobile broadband Internet access by improving spectral efficiency, lowering costs, improving services, making use of new spectrum, and better integrating with other open standards using OFDMA on the downlink (DL), SC-FDMA on the uplink (UL), and multiple-input multiple-output (MIMO) antenna technology. However, as the demand for mobile broadband access continues to increase, there exists a need for further improvements in LTE technology. Preferably, these improvements should be applicable to other multi-access technologies and the telecommunication standards that employ these technologies.

SUMMARY

In an aspect of the disclosure, a method, a computer program product, and an apparatus are provided. A method, an apparatus, and a computer program product for wireless communication are provided. The apparatus determines an observed bit rate based on uplink transmissions of the UE, estimates an available link capacity for the UE, selects an estimate factor, and estimates available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating an example of a network architecture.

FIG. **2** is a diagram illustrating an example of an access network.

FIG. **3** is a diagram illustrating an example of a DL frame structure in LTE.

FIG. **4** is a diagram illustrating an example of an UL frame structure in LTE.

FIG. **5** is a diagram illustrating an example of a radio protocol architecture for the user and control planes.

FIG. **6** is a diagram illustrating an example of an evolved Node B and user equipment in an access network.

FIG. **7** is an illustration of a wireless communication system including a UE communicating with a serving eNB to receive wireless network access.

FIG. **8** is a graph illustrating a burst of uplink transmissions during a period of time t, referred to herein as burst period.

FIG. **9** is a graph illustrating an example calculation of an observed bit rate (OBR) for an observation period based on a moving average of bit rates per burst period.

FIG. **10** is a graph illustrating an example calculation of OBR for an observation period based on a summation of scheduled bits and time periods.

FIG. **11** is a graph illustrating a calculation of OBR for an observation period that incorporates previous calculated ORBs.

FIG. **12** is a graph illustrating bit transmission rate in bits per second (bp/s) as a function of time, including various estimated bit transmission rates for a next burst period t.

FIG. **13** is a flow chart of a method of wireless communication.

FIG. **14** is a conceptual data flow diagram illustrating the data flow between different modules/means/components in an exemplary apparatus.

FIG. **15** is a diagram illustrating an example of a hardware implementation for an apparatus employing a processing system.

DETAILED DESCRIPTION

The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

Several aspects of telecommunication systems will now be presented with reference to various apparatus and methods. These apparatus and methods will be described in the following detailed description and illustrated in the accompanying drawings by various blocks, modules, components, circuits, steps, processes, algorithms, etc. (collectively referred to as "elements"). These elements may be implemented using electronic hardware, computer software, or any combination thereof. Whether such elements are implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system.

By way of example, an element, or any portion of an element, or any combination of elements may be implemented with a "processing system" that includes one or more processors. Examples of processors include microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. One or more processors in the processing system may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise.

Accordingly, in one or more exemplary embodiments, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or encoded as one or more instructions or code on a computer-readable medium. Computer-readable media includes computer storage media. Storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise a random-access memory (RAM), a read-only memory (ROM), an electrically erasable programmable ROM (EEPROM), compact disk ROM (CD-ROM) or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, includes CD, laser disc, optical disc, digital versatile disc (DVD), and floppy disk where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

FIG. **1** is a diagram illustrating an LTE network architecture **100**. The LTE network architecture **100** may be referred to as an Evolved Packet System (EPS) **100**. The EPS **100** may include one or more user equipment (UE) **102**, an Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) **104**, an Evolved Packet Core (EPC) **110**, and an Operator's Internet Protocol (IP) Services **122**. The EPS can interconnect with other access networks, but for simplicity those entities/interfaces are not shown. As shown, the EPS provides packet-switched services, however, as those skilled in the art will readily appreciate, the various concepts presented throughout this disclosure may be extended to networks providing circuit-switched services.

The E-UTRAN includes the evolved Node B (eNB) **106**, other eNBs **108**, and a Multicast Coordination Entity (MCS) **128**. The eNB **106** provides user and control planes protocol terminations toward the UE **102**. The eNB **106** may be connected to the other eNBs **108** via a backhaul (e.g., an X2 interface). The MCE **128** allocates time/frequency radio resources for evolved Multimedia Broadcast Multicast Service (MBMS) (eMBMS), and determines the radio configuration (e.g., a modulation and coding scheme (MCS)) for the eMBMS. The MCE **128** may be a separate entity or part of the eNB **106**. The eNB **106** may also be referred to as a base station, a Node B, an access point, a base transceiver station, a radio base station, a radio transceiver, a transceiver function, a basic service set (BSS), an extended service set (ESS), or some other suitable terminology. The eNB **106** provides an access point to the EPC **110** for a UE **102**. Examples of UEs **102** include a cellular phone, a smart phone, a session initiation protocol (SIP) phone, a laptop, a personal digital assistant (PDA), a satellite radio, a global positioning system, a multimedia device, a video device, a digital audio player (e.g., MP3 player), a camera, a game console, a tablet, or any other similar functioning device. The UE **102** may also be referred to by those skilled in the art as a mobile station, a subscriber station, a mobile unit, a subscriber unit, a wireless unit, a remote unit, a mobile device, a wireless device, a wireless communications device, a remote device, a mobile subscriber station, an access terminal, a mobile terminal, a wireless terminal, a remote terminal, a handset, a user agent, a mobile client, a client, or some other suitable terminology.

The eNB **106** is connected to the EPC **110**. The EPC **110** may include a Mobility Management Entity (MME) **112**, a Home Subscriber Server (HSS) **120**, other MMEs **114**, a Serving Gateway **116**, a Multimedia Broadcast Multicast Service (MBMS) Gateway **124**, a Broadcast Multicast Service Center (BM-SC) **126**, and a Packet Data Network (PDN) Gateway **118**. The MME **112** is the control node that processes the signaling between the UE **102** and the EPC **110**. Generally, the MME **112** provides bearer and connection management. All user IP packets are transferred through the Serving Gateway **116**, which itself is connected to the PDN Gateway **118**. The PDN Gateway **118** provides UE IP address allocation as well as other functions. The PDN Gateway **118** and the BM-SC **126** are connected to the IP Services **122**. The IP Services **122** may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service (PSS), and/or other IP services. The BM-SC **126** may provide functions for MBMS user service provisioning and delivery. The BM-SC **126** may serve as an entry point for content provider MBMS transmission, may be used to authorize and initiate MBMS Bearer Services within a PLMN, and may be used to schedule and deliver MBMS transmissions. The MBMS Gateway **124** may be used to distribute MBMS traffic to the eNBs (e.g., **106**, **108**) belonging to a Multicast Broadcast Single Frequency Network (MBSFN) area broadcasting a particular service, and may be responsible for session management (start/stop) and for collecting eMBMS related charging information.

FIG. **2** is a diagram illustrating an example of an access network **200** in an LTE network architecture. In this example, the access network **200** is divided into a number of cellular regions (cells) **202**. One or more lower power class eNBs **208** may have cellular regions **210** that overlap with one or more of the cells **202**. The lower power class eNB **208** may be a femto cell (e.g., home eNB (HeNB)), pico cell, micro cell, or remote radio head (RRH). The macro eNBs **204** are each assigned to a respective cell **202** and are configured to provide an access point to the EPC **110** for all the UEs **206** in the cells **202**. There is no centralized controller in this example of an access network **200**, but a centralized controller may be used in alternative configurations. The eNBs **204** are responsible for all radio related functions including radio bearer control, admission control, mobility control, scheduling, security, and connectivity to the serving gateway **116**. An eNB may support one or multiple (e.g., three) cells (also referred to as a sector). The term "cell" can refer to the smallest coverage area of an eNB and/or an eNB subsystem serving are particular coverage area. Further, the terms "eNB," "base station," and "cell" may be used interchangeably herein.

The modulation and multiple access scheme employed by the access network **200** may vary depending on the particular telecommunications standard being deployed. In LTE applications, OFDM is used on the DL and SC-FDMA is used on the UL to support both frequency division duplex (FDD) and time division duplex (TDD). As those skilled in the art will readily appreciate from the detailed description to follow, the various concepts presented herein are well suited for LTE applications. However, these concepts may be readily extended to other telecommunication standards employing other modulation and multiple access techniques. By way of example, these concepts may be extended to Evolution-Data Optimized (EV-DO) or Ultra Mobile Broadband (UMB). EV-DO and UMB are air interface standards promulgated by the 3rd Generation Partnership Project 2 (3GPP2) as part of the CDMA2000 family of standards and employs CDMA to provide broadband Internet access to mobile stations. These concepts may also be extended to Universal Terrestrial Radio Access (UTRA) employing Wideband-CDMA (W-CDMA) and other variants of CDMA, such as TD-SCDMA; Global System for Mobile Communications (GSM) employing TDMA; and Evolved UTRA (E-UTRA), IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20, and Flash-OFDM employing OFDMA. UTRA, E-UTRA, UMTS, LTE and GSM are described in documents from the 3GPP organization. CDMA2000 and UMB are described in documents from the 3GPP2 organization. The actual wireless communication standard and the multiple access technology employed will depend on the specific application and the overall design constraints imposed on the system.

The eNBs **204** may have multiple antennas supporting MIMO technology. The use of MIMO technology enables the eNBs **204** to exploit the spatial domain to support spatial multiplexing, beamforming, and transmit diversity. Spatial multiplexing may be used to transmit different streams of data simultaneously on the same frequency. The data streams may be transmitted to a single UE **206** to increase the data rate or to multiple UEs **206** to increase the overall system capacity. This is achieved by spatially precoding each data stream (e.g, applying a scaling of an amplitude and a phase) and then transmitting each spatially precoded stream through multiple transmit antennas on the DL. The spatially precoded data streams arrive at the UE(s) **206** with different spatial signatures, which enables each of the UE(s) **206** to recover the one or more data streams destined for that UE **206**. On the UL, each UE **206** transmits a spatially precoded data stream, which enables the eNB **204** to identify the source of each spatially precoded data stream.

Spatial multiplexing is generally used when channel conditions are good. When channel conditions are less favorable, beamforming may be used to focus the transmission energy in one or more directions. This may be achieved by spatially precoding the data for transmission through multiple antennas. To achieve good coverage at the edges of the cell, a single stream beamforming transmission may be used in combination with transmit diversity.

In the detailed description that follows, various aspects of an access network will be described with reference to a MIMO system supporting OFDM on the DL. OFDM is a spread-spectrum technique that modulates data over a number of subcarriers within an OFDM symbol. The subcarriers are spaced apart at precise frequencies. The spacing provides “orthogonality” that enables a receiver to recover the data from the subcarriers. In the time domain, a guard interval (e.g., cyclic prefix) may be added to each OFDM symbol to combat inter-OFDM-symbol interference. The UL may use SC-FDMA in the form of a DFT-spread OFDM signal to compensate for high peak-to-average power ratio (PAPR).

FIG. **3** is a diagram **300** illustrating an example of a DL frame structure in LTE. A frame (10 ms) may be divided into 10 equally sized subframes. Each subframe may include two consecutive time slots. A resource grid may be used to represent two time slots, each time slot including a resource block. The resource grid is divided into multiple resource elements. In LTE, a resource block contains 12 consecutive subcarriers in the frequency domain and, for a normal cyclic prefix in each OFDM symbol, 7 consecutive OFDM symbols in the time domain, or 84 resource elements. For an extended cyclic prefix, a resource block contains 6 consecutive OFDM symbols in the time domain and has 72 resource elements. Some of the resource elements, indicated as R **302**, **304**, include DL reference signals (DL-RS). The DL-RS include Cell-specific RS (CRS) (also sometimes called common RS) **302** and UE-specific RS (UE-RS) **304**. UE-RS 304 are transmitted only on the resource blocks upon which the corresponding physical DL shared channel (PDSCH) is mapped. The number of bits carried by each resource element depends on the modulation scheme. Thus, the more resource blocks that a UE receives and the higher the modulation scheme, the higher the data rate for the UE.

FIG. **4** is a diagram **400** illustrating an example of an UL frame structure in LTE. The available resource blocks for the UL may be partitioned into a data section and a control section. The control section may be formed at the two edges of the system bandwidth and may have a configurable size. The resource blocks in the control section may be assigned to UEs for transmission of control information. The data section may include all resource blocks not included in the control section. The UL frame structure results in the data section including contiguous subcarriers, which may allow a single UE to be assigned all of the contiguous subcarriers in the data section.

A UE may be assigned resource blocks **410***a*, **410***b* in the control section to transmit control information to an eNB. The UE may also be assigned resource blocks **420***a*, **420***b* in the data section to transmit data to the eNB. The UE may transmit control information in a physical UL control channel (PUCCH) on the assigned resource blocks in the control section. The UE may transmit only data or both data and control information in a physical UL shared channel (PUSCH) on the assigned resource blocks in the data section. A UL transmission may span both slots of a subframe and may hop across frequency.

A set of resource blocks may be used to perform initial system access and achieve UL synchronization in a physical random access channel (PRACH) **430**. The PRACH **430** carries a random sequence and cannot carry any UL data/signaling. Each random access preamble occupies a bandwidth corresponding to six consecutive resource blocks. The starting frequency is specified by the network. That is, the transmission of the random access preamble is restricted to certain time and frequency resources. There is no frequency hopping for the PRACH. The PRACH attempt is carried in a single subframe (1 ms) or in a sequence of few contiguous subframes and a UE can make only a single PRACH attempt per frame (10 ms).

FIG. **5** is a diagram **500** illustrating an example of a radio protocol architecture for the user and control planes in LTE. The radio protocol architecture for the UE and the eNB is shown with three layers: Layer 1, Layer 2, and Layer 3. Layer 1 (L1 layer) is the lowest layer and implements various physical layer signal processing functions. The L1 layer will be referred to herein as the physical layer **506**.

Layer 2 (L2 layer) **508** is above the physical layer **506** and is responsible for the link between the UE and eNB over the physical layer **506**.

In the user plane, the L2 layer **508** includes a media access control (MAC) sublayer **510**, a radio link control (RLC) sublayer **512**, and a packet data convergence protocol (PDCP) **514** sublayer, which are terminated at the eNB on the network side. Although not shown, the UE may have several upper layers above the L2 layer **508** including a network layer (e.g., IP layer) that is terminated at the PDN gateway **118** on the network side, and an application layer that is terminated at the other end of the connection (e.g., far end UE, server, etc.).

The PDCP sublayer **514** provides multiplexing between different radio bearers and logical channels. The PDCP sublayer **514** also provides header compression for upper layer data packets to reduce radio transmission overhead, security by ciphering the data packets, and handover support for UEs between eNBs. The RLC sublayer **512** provides segmentation and reassembly of upper layer data packets, retransmission of lost data packets, and reordering of data packets to compensate for out-of-order reception due to hybrid automatic repeat request (HARQ). The MAC sublayer **510** provides multiplexing between logical and transport channels. The MAC sublayer **510** is also responsible for allocating the various radio resources (e.g., resource blocks) in one cell among the UEs. The MAC sublayer **510** is also responsible for HARQ operations.

In the control plane, the radio protocol architecture for the UE and eNB is substantially the same for the physical layer **506** and the L2 layer **508** with the exception that there is no header compression function for the control plane. The control plane also includes a radio resource control (RRC) sublayer **516** in Layer 3 (L3 layer). The RRC sublayer **516** is responsible for obtaining radio resources (e.g., radio bearers) and for configuring the lower layers using RRC signaling between the eNB and the UE.

FIG. **6** is a block diagram of an eNB **610** in communication with a UE **650** in an access network. In the DL, upper layer packets from the core network are provided to a controller/processor **675**. The controller/processor **675** implements the functionality of the L2 layer. In the DL, the controller/processor **675** provides header compression, ciphering, packet segmentation and reordering, multiplexing between logical and transport channels, and radio resource allocations to the UE **650** based on various priority metrics. The controller/processor **675** is also responsible for HARQ operations, retransmission of lost packets, and signaling to the UE **650**.

The transmit (TX) processor **616** implements various signal processing functions for the L1 layer (e.g, physical layer). The signal processing functions include coding and interleaving to facilitate forward error correction (FEC) at the UE **650** and mapping to signal constellations based on various modulation schemes (e.g., binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols are then split into parallel streams. Each stream is then mapped to an OFDM subcarrier, multiplexed with a reference signal (e.g., pilot) in the time and/or frequency domain, and then combined together using an Inverse Fast Fourier Transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator **674** may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal and/or channel condition feedback transmitted by the UE **650**. Each spatial stream may then be provided to a different antenna **620** via a separate transmitter **618**TX. Each transmitter **618**TX may modulate an RF carrier with a respective spatial stream for transmission.

At the UE **650**, each receiver **654**RX receives a signal through its respective antenna **652**. Each receiver **654**RX recovers information modulated onto an RF carrier and provides the information to the receive (RX) processor **656**. The RX processor **656** implements various signal processing functions of the L1 layer. The RX processor **656** may perform spatial processing on the information to recover any spatial streams destined for the UE **650**. If multiple spatial streams are destined for the UE **650**, they may be combined by the RX processor **656** into a single OFDM symbol stream. The RX processor **656** then converts the OFDM symbol stream from the time-domain to the frequency domain using a Fast Fourier Transform (FFT). The frequency domain signal comprises a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the eNB **610**. These soft decisions may be based on channel estimates computed by the channel estimator **658**. The soft decisions are then decoded and deinterleaved to recover the data and control signals that were originally transmitted by the eNB **610** on the physical channel. The data and control signals are then provided to the controller/processor **659**.

The controller/processor **659** implements the L2 layer. The controller/processor can be associated with a memory **660** that stores program codes and data. The memory **660** may be referred to as a computer-readable medium. In the UL, the controller/processor **659** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover upper layer packets from the core network. The upper layer packets are then provided to a data sink **662**, which represents all the protocol layers above the L2 layer. Various control signals may also be provided to the data sink **662** for L3 processing. The controller/processor **659** is also responsible for error detection using an acknowledgement (ACK) and/or negative acknowledgement (NACK) protocol to support HARQ operations.

In the UL, a data source **667** is used to provide upper layer packets to the controller/processor **659**. The data source **667** represents all protocol layers above the L2 layer. Similar to the functionality described in connection with the DL transmission by the eNB **610**, the controller/processor **659** implements the L2 layer for the user plane and the control plane by providing header compression, ciphering, packet segmentation and reordering, and multiplexing between logical and transport channels based on radio resource allocations by the eNB **610**. The controller/processor **659** is also responsible for HARQ operations, retransmission of lost packets, and signaling to the eNB **610**.

Channel estimates derived by a channel estimator **658** from a reference signal or feedback transmitted by the eNB **610** may be used by the TX processor **668** to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the TX processor **668** may be provided to different antenna **652** via separate transmitters **654**TX. Each transmitter **654**TX may modulate an RF carrier with a respective spatial stream for transmission.

The UL transmission is processed at the eNB **610** in a manner similar to that described in connection with the receiver function at the UE **650**. Each receiver **618**RX receives a signal through its respective antenna **620**. Each receiver **618**RX recovers information modulated onto an RF carrier and provides the information to a RX processor **670**. The RX processor **670** may implement the L1 layer.

The controller/processor **675** implements the L2 layer. The controller/processor **675** can be associated with a memory **676** that stores program codes and data. The memory **676** may be referred to as a computer-readable medium. In the UL, the controller/processor **675** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover upper layer packets from the UE **650**. Upper layer packets from the controller/processor **675** may be provided to the core network. The controller/processor **675** is also responsible for error detection using an ACK and/or NACK protocol to support HARQ operations.

FIG. **7** is an illustration **700** of a wireless communication system including a UE **702** communicating with a serving eNB **704** to receive wireless network access. As part of wireless network access, the scheduler **714** of the serving eNB **704** grants the UE **702** uplink resources **710** for uplink transmissions. The quantity of uplink resources **710** granted to a UE **702** for uplink transmissions may vary, for example, as a function of the number of UEs being served by the serving eNB **704**. Applications on a UE **702** may adjust operations in accordance with the amount of uplink resources granted to the UE. For example, if an application wants to transmit video data but insufficient resources are granted, the application may delay transmission until enough uplink resources are available. It would be beneficial for a UE **702** to have an indication or estimate of future uplink throughput, so applications may adjust in advance.

In an aspect, a UE **702** includes an uplink throughput estimator **706** that predicts or estimates available uplink throughput for future uplink transmissions. In one aspect, the uplink throughput estimation is a function of an observed bit rate (OBR) derived based on past scheduled uplink transmission grants to the UE, and a long term factor that is based on an estimate of link capacity and a selected estimate factor. The uplink throughput estimator **706** provides an estimate of uplink throughput to a processor/application **708**. Based on the uplink throughput estimation, the processor/application **708** may adjust its operation and transmit uplink data **712** to the serving eNB **704**.

In one configuration, the uplink throughput estimation is defined as:

$$\text{Estimated available total rate}=\text{Max}(OBR\text{*long term factor},GBR,\text{Minimum}BR), \quad \text{(Eq. 1)}$$

where:

OBR=observed bit rate (for a past/previous observation period T);

long term factor=estimate factor (E)*(link capacity/OBR);

GRB=guaranteed bit rate;

MinimumBR=0 or 2 kbps.

Observed Bit Rate

As noted above, the OBR is based on past scheduled uplink transmission grants. FIG. **8** is a graph **800** illustrating a number of scheduled uplink transmission grants **802** occurring during a period of time ti. The uplink transmission grants **802** within the time period ti are collectively referred to as a "burst" **804** of uplink transmission grants and the time period ti is referred to as a "burst period" **806**. The burst period ti **806** may be part of a longer time period T (not shown), referred to as an observation period. Although only one burst period **806** is shown in FIG. **8**, as explained below, an observation period T may include more than one burst period.

Continuing with reference to FIG. **8**, each vertical bar within the burst period ti **806** corresponds to a particular UL transmission grant, and the height of the bar reflects the number of bits scheduled to be transmitted during the particular UL transmission grant. An UL transmission grant may start when the UE has data to transmit, e.g, when the UE indicates to the network that the UE has data to transmit, and may end when the UE buffer is empty, e.g, all data to be transmitted by the UE has been transmitted. An OBR during the burst period ti **806** is derived, for example, by summing the number of bits transmitted during each UL transmission grant **802** to arrive at a total number of bits transmitted during the burst period ti **806** and dividing the total number of bits by time ti.

In accordance with concepts disclosed herein, OBR calculations may be based on a number of burst periods ti occurring during an observation period T. In one implementation, the OBR for an observation period may be based on a moving average of the number of scheduled bits in each burst period ti. In this case, the OBR may be generally expressed as follows:

$$OBR=\text{moving average of ((scheduled bits } bi \text{ during } ti)/(ti)) \quad \text{(Eq. 2)}$$

FIG. **9** is a graph **900** illustrating an example calculation of an OBR for an observation period T **902** based on a moving average of bit rates per burst period. In this example, the observation period T **902** includes three burst periods t**1**, t**2** and t**3**. A first average **904** is calculated based on the bit rate of a first burst period t**1** and the bit rate of a second burst period t**2**. The bit rate for a burst period t may be calculated as the total number of bits b scheduled during the burst period, divided by the period. A second average **906** is then calculated based on the first average **904** and the bit rate of the third burst period t**3**. The second average **906** is the OBR for the observation period T.

In another implementation, the OBR for an observation period may be based on summations of scheduled bits and burst periods. In this case, the OBR may be generally expressed as follows:

$$OBR=\text{((sum of scheduled bits } bi \text{ during } ti)/(\text{sum of } ti)) \quad \text{(Eq. 3)}$$

FIG. **10** is a graph **1000** illustrating an example calculation of OBR for an observation period T **1002** based on a summation of scheduled bits and burst periods. In this example, the observation period T **1002** includes three burst periods t**1**, t**2** and t**3**. The OBR **1004** for the observation period T **1002** may be calculated as the summation of bits scheduled during each burst period, divided by the summation of burst periods.

In another implementation, the OBR for an observation period may be based on a moving average that involves previously determined OBRs. In this case, the OBR may be generally expressed as follows:

$$OBR=\text{moving average of ((sum of scheduled bits } bi \text{ during } ti)/(\text{sum of } ti)) \quad \text{(Eq. 4)}$$

FIG. **11** is a graph **1100** illustrating a calculation of OBR **1108** for an observation period T(n) **1102** that incorporates previous calculated ORBs. A previous OBR **1104** for an observation period T(n−1) **1106** is assumed to have been calculated. During a subsequent observation period T(n) **1102** a number of complete burst periods t**1** through t**3** are present along with a portion tN of a burst period that carries over into the next observation period. During each burst period t**1** through t**3** and burst-period portion tN a number of scheduled uplink transmissions **1110** occur, as represented by the vertical bars. The number of bits in each uplink transmission **1110** is summed to arrive at a total number of bits bi transmitted during the period ti. This is repeated for each burst period t**1** through t**3** and burst-period portion tN in the second observation period T(n). The total number of bits b**1** through b**3** in burst periods t**1** through t**3** and the number of bits bN in burst-period portion tN are summed and divided by the total time of burst periods t**1** through t**3** and burst-period portion tN. In one configuration, the OBR **1108** for observation period T(n) **1102** is calculated as an exponential moving average using the following equations:

$$(\alpha.OBR_n+(1+\alpha).OBR_{n-1}) \quad \text{(Eq. 5)}$$

and

$$OBR_{T(n)}=\alpha.\frac{\sum bi}{\sum ti}+(1-\alpha.).OBR_{T(n-1)} \quad \text{(Eq. 6)}$$

where α may be any value, and in one configuration, is greater than or equal to zero and less than or equal to 1.

In one aspect, an OBR is calculated when the number of bits in the scheduled uplink transmissions exceeds a threshold corresponding to a significant amount of data. For example, the threshold number of bits may be 60 bytes. The threshold bit requirement is beneficial in that it can discount one shot transmission, such as silence indicator (SID) in LTE and transmission control protocol ACKs.

With respect to the burst periods, the start and end of a burst period may be based on communication events that may occur while the UE is in a connected mode. In one aspect, a burst period ti starts at the beginning of an uplink burst. The beginning of an uplink burst may correspond to, for example, one of: 1) transmission of a scheduling request (SR) by the UE, 2) transmission of a buffer status report (BSR) by the UE, 3) transmission of a random access channel request (RACH) by the UE, 4) the start of an "active time" timer in a UE after wake up by the UE during DXR mode, 5) the start of semi-persistent scheduling (SPS), 6) the reception of an uplink grant, 7) the presence of data in the uplink transmission buffer, or 8) the beginning of an observation period T when the UE outgoing data buffer is not empty. With respect to observation periods, these periods are repeated periodically back to back, meaning that a next observation period begins when the previous observation period expires. A first observation period in a series of back-to-back observation periods starts when the rate estimation starts, either when triggered by the upper layers or at the beginning of the RRC connection.

In one implementation, the first burst period during an observation period starts at the earliest of the foregoing communication events 1), 2), 3), 4), 5) or 6). The subsequent burst periods start at the earliest of the foregoing communication events 1), 2), 3), 4) or 5). In another implementation, the first burst period during an observation period starts at the earliest of the foregoing communication events 1), 2), 3), 6) or 7).

In another aspect, the burst periods ti may end when: 1) the UE no longer has data to transmit, such as when the UE buffer is empty, 2) the "active time" timer of the UE expires and the UE goes to sleep, 3) SPS ends, and 4) the observation period T ends. In one implementation, a burst period is considered to end at the earliest of the foregoing communication events. In another implementation, a burst period is considered to end when the UE buffer no longer has data to transmit. In most cases, a last amount of leftover data remains in the buffer to be transmitted by a UE, such that the network grants a small number of resources to the UE. This occurs often as the grant size is quantized and may not equal exactly the amount of leftover data, and in some cases the networks prefer to send a larger grant to take into account newly arrived data that was not included in the last BSR. In this case, the burst period may end upon transmission of the last transmission of data before the small transmission that empties the buffer. This removes the small number of scheduled bits from the overall estimate of uplink throughput and thus provides a more meaningful uplink throughput estimate.

In another implementation, the OBR for an observation period may be based on a moving average that involves BSRs. In this case, the OBR may be generally expressed as follows:

$$OBR=\text{moving average of ((reported } BSR \text{ total)/(}T\text{))} \quad \text{(Eq. 7)}$$

In this case, the UE indicates to the network through a BSR the amount of data the UE has to transmit. Time T is the time it takes to transmit the data after the BSR was reported. This implementation may be used when the amount of data indicated in the BSR exceeds a threshold. For example, when more than 100 bytes arrive at the UE transmission buffers, an SR may be sent to inform the network of pending data. The eNB may send a grant to get some of the data transmitted, but also to retrieve the BSR thereby allowing for an accounting of the data to be transmitted.

Long Term Factor

The "long term factor" parameter of the estimated available total rate (Eq. 1) may be expressed as follows:

$$\text{long term factor}=\text{estimate factor}(E)*(LC/OBR) \quad \text{(Eq. 8)}$$

where:

LC=estimated link capacity;

E=estimate factor.

Link Capacity:

Regarding the link capacity (LC) parameter of the long term factor calculation, an estimate of LC may be obtained as follows:

$$\text{Link Capacity}=\text{Max(efficiency*maximum rate, sum of all } GBR) \quad \text{(Eq. 9)}$$

The efficiency parameter may be fixed or calculated. For example, efficiency may be fixed at 0.9, to take into account the impact of the typical 10% error on a transmission. Efficiency may be calculated based on retransmission acknowledgments. For example, calculated efficiency may be obtained as follows:

$$\text{Calculated efficiency}=\text{(number of ACKs)/(number of uplink transmissions, including retransmissions)} \quad \text{(Eq. 10)}$$

The maximum rate corresponds to a measure of the maximum bit rate available to the UE under current radio conditions, e.g., transmission and power headroom (PHR) conditions, and assuming all possible resource blocks are allocated in a subframe. In one aspect, a measure of the maximum rate may be calculated using known techniques based on the modulation and coding scheme (MCS) of previous transmissions. The MCS gives the modulation and coding for all the radio blocks (RB). In one implementation, we assume that the UE could be granted the maximum number of RBs. In another implementation, it is assumed that the eNB continues to receive the same average grant size in terms of the past number of RBs as the recent history. Possible MCSs used in the calculation include: the last granted MCS, the MCS most granted in the recent past, and the average of maximum rates calculated using recently granted MCSs.

In another aspect, a measure of the maximum rate may be calculated as the maximum possible RBs (M_{PUSCH_max}) using the following:

$$10\log(M_{PUSCH\_max})=P_{cMAX}-P_{O\_PUSCH}(j)-\alpha_c*PL_c-f(i) \quad \text{(Eq. 11)}$$

where P_{cMAX}, $P_{O\_PUSCH}(j)$, α_c, PL_c and f(i) are parameters described in 3GPP TS 36.213, version 11.4.0, section 5.1.1.1.

Estimate Factor

FIG. **12** is a graph **1200** illustrating bit transmission rate in bits per second (bp/s) as a function of time within an observation period T. The bit rate value "a" **1202** on the vertical axis corresponds to the observed bit rate calculated for the uplink scheduled transmission grants during the burst period ti **806** of FIG. **8**. The end of the burst period ti **806** is further indicated by point "a" in FIG. **8**. Returning to FIG. **12**, the bit rate value "b" corresponds to a linear extrapolation of the bit rate calculated for the uplink transmissions ending at point "a" in FIG. **8**, under the assumption that the network will grant uplink transmission grants having a number of bits similar to uplink grant **808**, for the entire observation period T **810**. The bit rate value "c" corresponds to an extrapolation of the bit rate calculated for the uplink transmission ending at point "a" in FIG. **8**, under the assumption that the network will grant uplink transmission grants corresponding to an estimate of the maximum grant that the network would give the UE under the current radio conditions.

Depending on the selected estimate factor, bit rate estimations for a point in time after t **1218**, may be either the bit rate "a" **1202** or bit rate "b" **1204**, or a bit rate corresponding to a value that lies along line "d" **1214**. In this case, the estimated bit rate may be between a value less than bit rate "a" and a value corresponding to bit rate "b". The estimated bit rate may also be the bit rate corresponding to bit rate "a" **1202** or bit rate "c" **1206**, or a bit rate corresponding to a value that lies along line "e" **1216**. In this case, the estimated bit rate may be between a value less than bit rate "a" and a value corresponding to bit rate "c".

The estimate factor (E) may be either statically chosen or dynamically changing. The estimate factor (E) may be statically equal to any one of the following special values Ea, Eb or Ec:

Ea=(OBR/LC)*(t/T), where T=observation period, and t=aggregate time the UE is transmitting during the observation period: When the estimate factor is Ea=(OBR/LC)*(t/T), the long term factor E*(LC/OBR) reduces to t/T, and the estimated available total rate OBR*long term factor becomes ORB*t/T. In this case, the estimated available bit rate is the transmitted bit rate "a" over all time, as shown by the horizontal line **1208** extending from "a" **1202** in FIG. **12**.

Eb=(OBR/LC): When the estimate factor is Eb=(OBR/LC), the long term factor E*(LC/OBR) reduces to 1, and the estimated available total rate OBR*long term factor becomes ORB. In this case, it is assumed that the OBR "b" can be sustained over all time, as shown by the horizontal line **1210** extending from "b" **1204** in FIG. **12**.

Ec=1: When the estimate factor is Ec=1, the, the long term factor E*(LC/OBR) reduces to LC/ORB, and the estimated available total rate OBR*long term factor becomes LC. In this case, it is assumed that the link capacity "c" can be sustained over all time, as shown by the horizontal line **1212** extending from "c" **1206** in FIG. **12**.

Alternatively, the estimate factor (E) can be dynamically chosen to alternatively increase or decrease the estimated uplink capacity. The increase of estimated uplink capacity could be based in part on the uplink queue size, on the last burst rate, on how fast the queue is being emptied, or periodically. The decrease of estimated uplink capacity could be based in part on the uplink queue size, on the last burst rate, on how slow the queue is being emptied, or based on input from the application such as frozen frames were observed at the receiver. Furthermore, the estimate could be tied to recent past radio conditions, e.g., whether the radio conditions are getting better or worse. Dynamic estimate factors may involve scaling as follows:

E scaling in time: Ea<E<Eb: In this case, the UE probes the network for more throughput. For example, the UE may transmit a fake BSR indicating an amount of data greater than the amount of data the UE has to transmit. If the probe by the UE fails, e.g, the network does not provide more throughput, the estimate factor remains Ea, and in turn, the estimated available bit rate remains the transmitted bit rate "a" **1202** over all time, as shown by the horizontal line **1208** extending from "a" in FIG. **12**. If the network does provide more throughput, the estimate factor is a value that results in an estimated available rate value between "a" **1202** and "b" **1204** as shown by the line "d" **1214** in FIG. **12**.

E scaling in time and capacity: Ea<E<Ec: In this case, the UE probes the network for more throughput. If the probe by the UE fails, the estimate factor remains Ea, and in turn, the estimated available bit rate remains the transmitted bit rate "a" **1202** over all time, as shown by the horizontal line **1208** extending from "a" in FIG. **8**. If the network does provide more throughput, the estimate factor is a value that results in an estimated available rate value between "a" **1202** and "c" **1206** as shown by the line "e" **1216** in FIG. **12**.

Upon determining the OBR for the current observation period, estimating the available link capacity for the UE and selecting an estimate factor, the UE may estimate an available uplink throughput for future uplink transmissions by the UE as a function of the OBR, the link capacity and the estimate factor. The UE may report the estimated available uplink throughput to the application. In some cases, the UE may determine that the actual available uplink throughput is greater than the estimated available uplink throughput. The UE may indicate to the applications the possibility of a higher uplink throughput by increasing the estimated available total rate, or by setting a "Plus" flag in the interface that reports the throughput estimate to the applications.

The "Plus" flag could be set to True (+): 1) at the beginning of data call, before any data was transmitted, 2) when the past observed bit rate drops to zero, if there hasn't been any data to be transmitted recently, or 3) when the LC is much greater than the observed bit rate.

The cost of transmitting at the estimated available total rate is also reported. Cost in this regard refers to power consumed during UL transmission. In one implementation, cost is defined based on PUSCH power control parameters as:

$$C(i)=P_{O\_PUSCH,c}(j)+\alpha_c(j)\cdot PL_c+f_c(i) \quad \text{(Eq. 12)}$$

where $P_{O\_PUSCH,c}(j)$, $\alpha_c(j)$, PL_c and $f_c(i)$ are parameters described in 3GPP TS 36.213, version 11.4.0, section 5.1.1.1.

If C(i)<=−10→Low cost

If (C(i)>−10) && (C(i)<=5)→Medium cost

If C(i)>5→High cost

The thresholds −10 and 5 may be configurable. C(i) is not expected to change rapidly because the pathloss (PL) is filtered and the other parameters are controlled by the eNB. A moving average of C(i) may also be used.

FIG. **13** is a flow chart **1300** of a method of wireless communication. The method may be performed by a UE. At **1302**, the UE determines an OBR based on uplink transmissions of the UE. In one implementation, the OBR is based on scheduled uplink transmission grants and may correspond to a measure of bit rate for an observation period T including at least one burst period t having a start and an end. The start and the end may be based on communication event. For example, the communication event upon which the start of a burst period is based may correspond to the earliest of: transmission of a SR by the UE, 2) transmission of a BSR by the UE, 3) transmission of a RACH by the UE, 4) the start of an active-time timer in the UE, 5) the start of SPS, or 6) a reception of an uplink grant, or 7) a presence of data in an uplink transmit buffer of the UE. The communication event upon which the end is based may correspond to the earliest of: the UE no longer having data to transmit, 2) the active-time timer of the UE stops, 3) SPS ends, or 4) the observation period T ends. The OBR may be calculated as described above with reference to FIG. **8**, FIG. **9**, FIG. **10** and FIG. **11**, and may be based on a moving average of individual OBRs.

In another implementation, the OBR is based on may be based on BSRs and corresponds to a measure of the total number of bits reported in the BSRs as a function of an observation period T. In this case, the UE indicates to the network through a BSR the amount of data the UE has to transmit. Time T is the time it takes to transmit the data after the BSR was reported.

At **1304**, the UE estimates an available link capacity for the UE. The estimated available link capacity may be the maximum of an efficiency factor times a maximum rate, and a summation of all guaranteed bit rates. The available link capacity may be estimated based on modulation and coding schemes of previous uplink transmissions.

At **1306**, the UE selects an estimate factor. In one implementation, the estimate factor may be selected such that the estimated available uplink throughput corresponds to the observed bit rate. In another implementation, the estimate factor may be selected such that the estimated available uplink throughput corresponds to the link capacity. In other implementations, an initial estimate factor may be scaled to obtain an estimated available uplink throughput at values other than the observed bit rate and the link capacity. For example, an initial estimate factor may be scaled such that the estimated available uplink throughput is between a value less than the observed bit rate and a value corresponding to a bit rate extrapolated from the observed bit rate. In another example, an initial estimate factor may be scaled such that the estimated available uplink throughput is between a value less than the observed bit rate and a value corresponding to the estimated available link capacity.

At **1308**, the UE estimates available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor. The estimated available uplink throughput may be the maximum of the product of the observed bit rate and a long term factor, a guaranteed bit rate, and a minimum bit rate, wherein the long term factor is a function of the estimate factor.

FIG. **14** is a conceptual data flow diagram **1400** illustrating the data flow between different modules/means/components in an exemplary apparatus **1402**. The apparatus **1402** may be a UE. The apparatus **1402** includes an OBR determination module **1404**, a link capacity estimation module **1406**, an estimate factor module **1408**, and a UL throughput estimation module **1410**. The apparatus **1402** also includes a receiver module **1412** and a transmission module **1414**.

The OBR determination module **1404** determines an observed bit rate based on uplink transmissions of the UE. To this end, the OBR determination module **1404** may process scheduled uplink grants, received from an eNB **1450** through the receiver module **1412**, to determine an OBR. Alternatively, the OBR determination module **1404** may, in response to BSRs transmitted by the transmission module **1414**, determine the OBR based on the time it takes for the UE to transmit the number of bits indicated in the BSR.

The link capacity estimation module **1406** estimates an available link capacity

LC for the UE. The estimate factor module **1408** selects an estimate factor E. The UL throughput estimation module **1410** estimates available uplink throughput for future uplink transmissions of the UE as a function of the OBR, the estimated available LC, and the estimate factor E.

The apparatus may include additional modules that perform each of the steps of the algorithm in the aforementioned flow chart of FIG. **13**. As such, each step in the aforementioned flow charts of FIG. **13** may be performed by a module and the apparatus may include one or more of those modules. The modules may be one or more hardware components specifically configured to carry out the stated processes/algorithm, implemented by a processor configured to perform the stated processes/algorithm, stored within a computer-readable medium for implementation by a processor, or some combination thereof.

FIG. **15** is a diagram **1500** illustrating an example of a hardware implementation for an apparatus **1402'** employing a processing system **1514**. The processing system **1514** may be implemented with a bus architecture, represented generally by the bus **1524**. The bus **1524** may include any number of interconnecting buses and bridges depending on the specific application of the processing system **1514** and the overall design constraints. The bus **1524** links together various circuits including one or more processors and/or hardware modules, represented by the processor **1504**, the modules **1404**, **1406**, **1408**, **1410**, **1412**, **1414** and the computer-readable medium/memory **1506**. The bus **1524** may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further.

The processing system **1514** may be coupled to a transceiver **1510**. The transceiver **1510** is coupled to one or more antennas **1520**. The transceiver **1510** provides a means for communicating with various other apparatus over a transmission medium. The transceiver **1510** receives a signal from the one or more antennas **1520**, extracts information from the received signal, and provides the extracted information to the processing system **1514**. In addition, the transceiver **1510** receives information from the processing system **1514**, and based on the received information, generates a signal to be applied to the one or more antennas **1520**. The processing system **1514** includes a processor **1504** coupled to a computer-readable medium/memory

1506. The processor 1504 is responsible for general processing, including the execution of software stored on the computer-readable medium/memory 1506. The software, when executed by the processor 1504, causes the processing system 1514 to perform the various functions described supra for any particular apparatus. The computer-readable medium/memory 1506 may also be used for storing data that is manipulated by the processor 1504 when executing software. The processing system further includes at least one of the modules 1404, 1406, 1408, 1410, 1412 and 1414. The modules may be software modules running in the processor 1504, resident/stored in the computer readable medium/memory 1506, one or more hardware modules coupled to the processor 1504, or some combination thereof. The processing system 1514 may be a component of the UE 650 and may include the memory 660 and/or at least one of the TX processor 668, the RX processor 656, and the controller/processor 659.\

In one configuration, the apparatus 1402/1402' for wireless communication includes means determining an OBR based on uplink transmissions of the UE, means for estimating an available link capacity for the UE, means for selecting an estimate factor, and means for estimating available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor.

The aforementioned means may be one or more of the aforementioned modules of the apparatus 1402 and/or the processing system 1514 of the apparatus 1402' configured to perform the functions recited by the aforementioned means. As described supra, the processing system 1514 may include the TX Processor 668, the RX Processor 656, and the controller/processor 659. As such, in one configuration, the aforementioned means may be the TX Processor 668, the RX Processor 656, and the controller/processor 659 configured to perform the functions recited by the aforementioned means.

It is understood that the specific order or hierarchy of steps in the processes/flow charts disclosed is an illustration of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes/flow charts may be rearranged. Further, some steps may be combined or omitted. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any aspect described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects." Unless specifically stated otherwise, the term "some" refers to one or more. Combinations such as "at least one of A, B, or C," "at least one of A, B, and C," and "A, B, C, or any combination thereof" include any combination of A, B, and/or C, and may include multiples of A, multiples of B, or multiples of C. Specifically, combinations such as "at least one of A, B, or C," "at least one of A, B, and C," and "A, B, C, or any combination thereof" may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, where any such combinations may contain one or more member or members of A, B, or C. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed as a means plus function unless the element is expressly recited using the phrase "means for."

What is claimed is:

1. A method of wireless communication of a user equipment (UE), comprising:
- determining, by the UE, an observed bit rate based on uplink transmissions of the UE;
- estimating an available link capacity for the UE;
- selecting an estimate factor; and
- estimating an available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor, wherein the estimated available uplink throughput is a maximum of a product of the observed bit rate and a long term factor, a guaranteed bit rate, and a minimum bit rate, wherein the long term factor is a function of the estimate factor.

2. The method of claim 1, wherein the observed bit rate is based on scheduled uplink transmission grants and corresponds to a measure of bit rate for an observation period T including at least one burst period t having a start and an end, each of the start and the end being based on a communication event.

3. The method of claim 2, wherein the communication event upon which the start is based corresponds to an earliest of one or more of: 1) a transmission of a scheduling request (SR) by the UE, 2) a transmission of a buffer status report (BSR) by the UE, 3) a transmission of a random access channel request (RACH) by the UE, 4) a start of an active-time timer in the UE, 5) a start of semi-persistent scheduling (SPS), 6) a reception of an uplink grant, or 7) a presence of data in an uplink transmit buffer of the UE.

4. The method of claim 2, wherein the communication event upon which the end is based corresponds to an earliest of one or more of: 1) the UE not having data to transmit, 2) a stopping of an active-time timer of the UE, 3) an end of SPS, or 4) an end of the observation period T.

5. The method of claim 2, wherein the observed bit rate is an average of bit rates measured over a plurality of observation periods.

6. The method of claim 1, wherein the observed bit rate is based on BSRs and corresponds to a measure of a total number of bits reported in the BSRs as a function of a total time taken to transmit the total number of bits.

7. The method of claim 1, wherein the estimated available link capacity is a maximum of an efficiency factor times a maximum rate, and a summation of all guaranteed bit rates.

8. The method of claim 7, wherein the maximum rate is based on modulation and coding schemes of previous uplink transmissions.

9. The method of claim 1, wherein the estimate factor is selected such that the estimated available uplink throughput corresponds to the observed bit rate.

10. The method of claim 1, wherein the estimate factor is selected such that the estimated available uplink throughput corresponds to the estimated available link capacity.

11. The method of claim 1, wherein selecting an estimate factor comprises scaling an initial estimate factor such that the estimated available uplink throughput is between a value less than the observed bit rate and a value corresponding to a bit rate extrapolated from the observed bit rate.

12. The method of claim 1, wherein selecting an estimate factor comprises scaling an initial estimate factor such that the estimated available uplink throughput is between a value less than the observed bit rate and a value corresponding to the estimated available link capacity.

13. An apparatus for wireless communication, the apparatus being a user equipment (UE), comprising:

means for determining an observed bit rate based on uplink transmissions of the UE;

means for estimating an available link capacity for the UE;

means for selecting an estimate factor; and

means for estimating an available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor, wherein the estimated available uplink throughput is a maximum of a product of the observed bit rate and a long term factor, a guaranteed bit rate, and a minimum bit rate, wherein the long term factor is a function of the estimate factor.

14. The apparatus of claim 13, wherein the observed bit rate is based on scheduled uplink transmission grants and corresponds to a measure of bit rate for an observation period T including at least one burst period t having a start and an end, each of the start and the end being based on a communication event.

15. The apparatus of claim 14, wherein the communication event upon which the start is based corresponds to an earliest of one or more of: 1) a transmission of a scheduling request (SR) by the UE, 2) a transmission of a buffer status report (BSR) by the UE, 3) a transmission of a random access channel request (RACH) by the UE, 4) a start of an active-time timer in the UE, 5) a start of semi-persistent scheduling (SPS), 6) a reception of an uplink grant, or 7) a presence of data in an uplink transmit buffer of the UE.

16. The apparatus of claim 14, wherein the communication event upon which the end is based corresponds to an earliest of one or more of: 1) the UE not having data to transmit, 2) a stopping of an active-time timer of the UE, 3) an end of SPS, or 4) an end of the observation period T.

17. The apparatus of claim 14, wherein the observed bit rate is an average of bit rates measured over a plurality of observation periods.

18. The apparatus of claim 13, wherein the observed bit rate is based on BSRs and corresponds to a measure of a total number of bits reported in the BSRs as a function of a total time taken to transmit the total number of bits.

19. The apparatus of claim 13, wherein the estimated available link capacity is a maximum of an efficiency factor times a maximum rate, and a summation of all guaranteed bit rates.

20. The apparatus of claim 19, wherein the maximum rate is based on modulation and coding schemes of previous uplink transmissions.

21. The apparatus of claim 13, wherein the estimate factor is selected such that the estimated available uplink throughput corresponds to the observed bit rate.

22. The apparatus of claim 13, wherein the estimate factor is selected such that the estimated available uplink throughput corresponds to the estimated available link capacity.

23. The apparatus of claim 13, wherein the means for selecting an estimate factor is configured to scale an initial estimate factor such that the estimated available uplink throughput is between a value less than the observed bit rate and a value corresponding to a bit rate extrapolated from the observed bit rate.

24. The apparatus of claim 13, wherein the means for selecting an estimate factor is configured to scale an initial estimate factor such that the estimated available uplink throughput is between a value less than the observed bit rate and a value corresponding to the estimated available link capacity.

25. An apparatus for wireless communication, the apparatus being a user equipment (UE), comprising:

a memory; and

at least one processor coupled to the memory and configured to:

determine an observed bit rate based on uplink transmissions of the UE;

estimate an available link capacity for the UE;

select an estimate factor; and

estimate an available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor, wherein the estimated available uplink throughput is a maximum of a product of the observed bit rate and a long term factor, a guaranteed bit rate, and a minimum bit rate, wherein the long term factor is a function of the estimate factor.

26. A non-transitory computer-readable medium storing computer executable code, comprising code to:

determine an observed bit rate based on uplink transmissions of a user equipment (UE);

estimate an available link capacity for the UE;

select an estimate factor; and

estimate an available uplink throughput for future uplink transmissions of the UE as a function of the observed bit rate, the estimated available link capacity, and the estimate factor, wherein the estimated available uplink throughput is a maximum of a product of the observed bit rate and a long term factor, a guaranteed bit rate, and a minimum bit rate, wherein the long term factor is a function of the estimate factor.

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